

\_\_\_\_\_JEWEL CAVE NATIONAL MONUMENT  
WATER RESOURCES SCOPING REPORT

Water Resources Division  
and

Jewel Cave National Monument

Technical Report NPS/NRWRD/NRTR-94/36

NATIONAL PARK SERVICE  
Water Resources Division  
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Jewel Cave National Monument  
Water Resources Scoping Report


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and

Jewel Cave National Monument  
Custer, South Dakota

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December 1994

United States Department of the Interior  
National Park Service  
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## EXECUTIVE SUMMARY

Jewel Cave National Monument was set aside as a unit of the National Park System to protect the unique underground resources of a maze of containing over 100 miles of known cave passage, tightly packed, under approximately three square miles of land surface. Portions of the cave extend beyond the monument boundary, and more passages are regularly being discovered. The cave is very old, and developed under a series of environments that produced rare and unusual cave minerals.

Water is one of the most critical resource concerns facing the monument because it is a very effective vehicle for transporting contaminants from the land surface into the cave. The entire known cave lies above the water table, so water movement occurs as complex percolation through the unsaturated zone. The rapidity with which water can move from the surface to the interior of the cave has been demonstrated by past investigations. Direct pathways for contaminants have been confirmed between the cave and the wastewater system and the monument's parking lot on the surface.

Many water resource issues facing the monument are associated with contamination of groundwater. All of the visitor and administrative facilities in the monument are located over cave passages including: the visitors center, maintenance yard, employee housing, parking lot, and sewage lagoons. A state highway also passes through a portion of

the monument and over a portion of the cave.

Serious problems with the amount and quality of water reaching the cave have occurred when the wastewater system developed extensive leaks. Problems with the wastewater system have been corrected, but its location necessitates continued monitoring. Other significant issues include: an incomplete understanding of the link between surface and groundwater draining to the cave, potential contamination from the highway and parking lot, alterations in natural drainage patterns, water rights, and long-term viability of wells.

The water resource issues facing Jewel Cave National Monument can be addressed without preparation of a Water Resources Management Plan, at this time. Recommendations are made in this report for each of the significant issue areas. Six project statements are attached for proposed or ongoing actions. These statements will be inserted into the monument's Natural and Cultural Resource Management Plan in order to compete for funding.

Monitor Water Resources. A continuation of the current monitoring program, which should become a base-funded activity when the current project is complete.

Surface and Groundwater Interactions. Further investigations into the complex interactions of surface and groundwater flow.

Water Rights. Determining the status of water rights for the monument, and preparations for possible state adjudications.

Hydrologic Connections With Hell Canyon. An investigation into possible hydraulic connections between the surface and subsurface as indicated by sediment deposits in the cave.

Monitor Groundwater Level. Long term monitoring of groundwater levels in wells and the cave in order to protect water supplies and cave resources.

Restore Natural Hydrologic Patterns. Restoration of natural hydrology if significant disturbances are found in other investigations.

Other recommended actions include pursuing an outstanding resource waters designation through the state, additional monument staff to carry out the long-term monitoring and water management program, and implementing several proposed actions from the Draft General Management Plan.



# INTRODUCTION

This scoping report for water resources management was undertaken to provide an analysis of the water resources issues facing Jewel Cave National Monument and to assess the need for developing a full water resources management plan. The water resources of Jewel Cave are very limited yet critical to the continued natural function of the cave, and to monument operations.

Jewel Cave National Monument was first established on February 7, 1908, by a Presidential Proclamation which noted that the cave was worthy of preservation because it was of "scientific interest." The monument was managed by the U.S. Forest Service until 1933, when its administration was transferred to the National Park Service (NPS). It is now managed under the guidance of the National Park Service Organic Act as amended.

When the monument was established, and for many years thereafter, the cave was thought to be relatively small and notable only for the extensive calcite crystals that covered many of the walls. After exploration began in earnest in 1959, the cave was found to be much larger; the calcite covered walls were found to be remarkably extensive, and several new and very rare speleothems were discovered. These include delicate hydromagnesite balloons, helictites and scintillites. Jewel Cave was found to contain a remarkably complex and extensive network of passages, with more than 100 miles of passages having been recorded as residing under less than three square miles of land surface. This makes it the second longest cave in the

United States, and the fourth longest in the world.

As the extent of the cave was ascertained, it became clear that a majority of the cave lay outside of the monument boundaries. This was corrected for the most part, through a boundary revision and land exchange with the U.S. Forest Service in 1965 (P.L. 89-250). Exploration continued and soon more of the cave was found to be outside the monument boundaries. In order to protect these resources from intrusions from mining, the U.S. Forest Service requested a withdrawal from mineral entry under the 1872 Mining Law for the lands over known cave resources. The withdrawal was effective May 18, 1990, and will remain in effect for at least twenty years.

Water and its management are important at the monument for three reasons:

1. Water is an essential component of the cave environment because it was responsible for the initial cave formation and now remains a key factor in the formation, maintenance, and deterioration of speleothems. Any alteration in the amount or quality of water flowing through the cave could cause irreversible impacts to some cave formations.
2. Water, its acquisition and disposal, is necessary to provide for visitor use of the cave.
3. Water can be the predominant vehicle for carrying contaminants from the surface to the cave.

# WATER RESOURCES MANAGEMENT PLANNING

Water is an essential resource in every unit of the National Park System, whether sustaining natural ecosystems or recreation, or as potable water for visitor and employees. Sound management of water resources is essential for achieving the purposes of the National Park Service and the individual units. The NPS strives to maintain natural high-quality waters in accordance with applicable federal, state, and local laws and regulations. In addition, the NPS assures compliance with floodplain management and wetland protection requirements, and obtains and uses water for the park system in accordance with legal authority and due consideration of the needs of other water users.

Where water resource issues are particularly numerous or complex, a NPS unit may benefit by the preparation of a Water Resources Management Plan (WRMP). The WRMP is an enhancement of the

Natural and Cultural Resources Management Plan (RMP) for the monument. Water issues are examined in much greater detail than is possible in most RMPs, including a more thorough review of existing information, in-depth analysis of water resource issues, and the development of an action plan to address them. The WRMP is similar to the RMP in structure and purpose, so project statements developed for the former can be incorporated directly into the latter.

Parks are not required to develop a WRMP, and many can address their water resource issues very adequately in the RMP. Where water resource issues or management constraints are particularly numerous, complex or controversial, a WRMP is useful in providing an identification and analysis of information and issues, and presenting a coordinated action plan to address them.

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## DESCRIPTION OF WATER AND RELATED RESOURCES

### General Description

Jewel Cave is located on the southwestern slopes of the Black Hills of South Dakota. The cave is situated in the Mississippian Madison Formation. There are five levels of rectilinear passages superimposed one atop the other, creating a true three-dimensional maze. This complex arrangement supports the occurrence of over

100 miles of passage under only three square miles of land surface (see Figure 1).

Most of the known cave is within the current monument boundary, but recent exploration has found cave passages which extend beyond the boundary and onto Black Hills National Forest. Further exploration will undoubtedly result in more of the cave being discovered well beyond the boundaries



Figure 1  
**JEWEL CAVE NATIONAL MONUMENT**

JEWEL CAVE NATIONAL MONUMENT  
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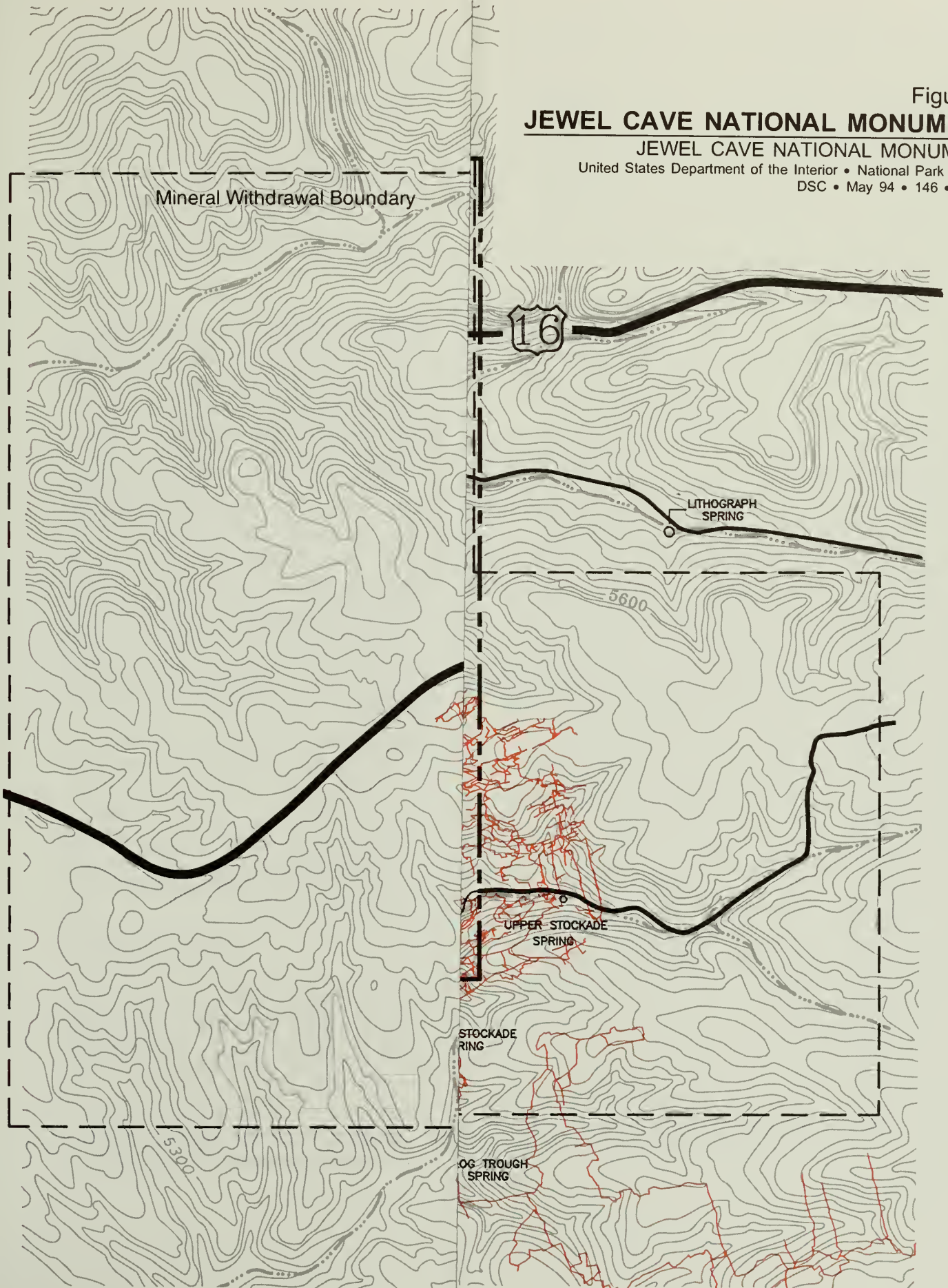
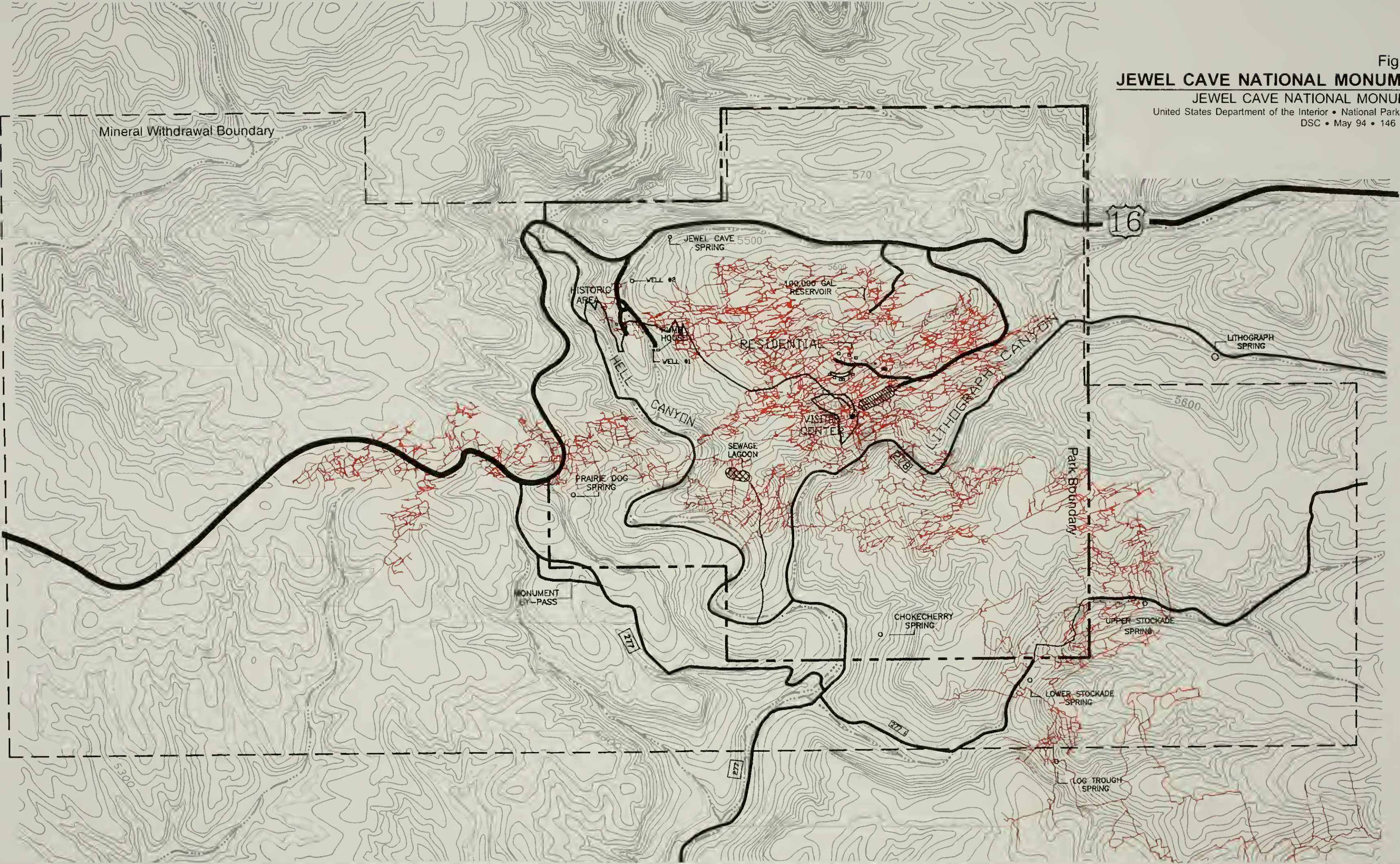




Figure 1  
**JEWEL CAVE NATIONAL MONUMENT**  
JEWEL CAVE NATIONAL MONUMENT  
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of the monument beneath U.S. Forest Service lands. Estimates of cave volume, based on air flow, indicate that only about 2% of the volume of Jewel Cave has been accounted for, thus 98% remains to be discovered (Wiles 1994). Air movements at the limits of the known cave indicate additional cave to the west, and much more to the south and east.

Portions of the cave were protected by mineral withdrawal with the establishment of the monument, and several small mineral withdrawals for various purposes in adjacent forest lands. A larger mineral withdrawal on adjacent Black Hills National Forest lands is currently being evaluated. Discoveries in 1992 found the cave extended beyond the current mineral withdrawal, and the known extent of the cave has increased since then. These portions of the cave might be subject to impacts from some future mining operation. No previous attempts have been made to use mining claims to gain access to Jewel Cave, but several other caves in the Black Hills have been successfully developed for cave tour businesses. Additional expansion of the mineral withdrawal may be necessary as the existence of more cave is confirmed or predicted with a reasonable degree of certainty.

## Geologic Setting

Jewel Cave is located along the southern slopes of the Black Hills uplift, a dome of raised strata roughly 100 miles by 60 miles. The uplift occurred as part of the Laramide Orogeny 60-70 million years ago. Subsequent erosion has removed several layers of sedimentary rock to

expose Precambrian metamorphic rocks in the central portion of the uplift. Where overlying sedimentary rocks remain, they are exposed in concentric rings of progressively younger strata dipping away from the Precambrian core.

Strata present in the vicinity of Jewel Cave are listed in Table 1, along with their hydrologic characteristics as described by Dyer (1961), Rahn and Gries (1973), and Wiles (1992). Several thousand feet of younger strata which have been eroded here still occur further away from the center of the uplift. The highest remaining formation is lower portion of the Minnelusa Formation exposed at the surface on higher terrain throughout the monument.

The Madison Formation is exposed only in the canyons and north of Jewel Cave Fault. The Madison Formation and Pahasapa Limestone are synonymous, and while the latter may more accurately describe local strata, the former is used in this report to allow wider recognition. All of the extensive cave passages found to date, are in the upper half of the Madison Formation.

The upper surface of the Madison Formation has been described as irregular, assumed to be the result of paleokarst development prior to deposition of the Minnelusa Formation, but observations by Wiles found very little topographic deviation. Wiles (1992) suggests that other observers were mistaking Yancey's "chert and limestone" unit of the Minnelusa, with the upper surface of the Madison. He



found the contact to be much more regular than previously described.

Strata below the Madison Formation are important as they affect the movement and availability of groundwater. Dyer (1961) described them in a report on drilling of the monument's first well. The Englewood Formation consists of about 40 feet of fossiliferous, massive, fine crystalline limestone. It has a very low porosity and did not yield any water when drilled for the monument's water supply wells. Below the Englewood Formation and above the Deadwood Formation is a 10-foot thick layer of coarse, poorly-sorted sandstone which apparently is not widely distributed in the Black Hills. This layer has a high degree of porosity and is the major aquifer for the monument's wells, and is under slight artesian pressure. In addition to dolomite and

limestone, the Deadwood Formation has layers of moderately porous sandstone, but these apparently did not yield much water. The deepest rocks penetrated by the well were Precambrian metamorphic rocks. These rocks typically have very low porosity and yield very little water unless extensively fractured.

The Jewel Cave Fault Zone includes at least two roughly parallel faults trending east-west across the northern portion of the monument. Strata on the south side of the fault have been displaced downward about 300 feet. U.S. Highway 16 takes advantage of the topographic breaks along this fault to traverse the area. It is thought that the faults block further exploration of the cave to the north and it is not known if extensive cave passages exist north of the fault.

Table 1. Geologic profile in the vicinity of Jewel Cave.

Strata	Age	Thickness (Feet)	Composition	Hydrologic Properties
Minnelusa Formation	Pennsylvanian	200 Total	Three units of uniform thickness at JECA, dissected by canyons	
		110	Upper Unit - Sandstone, siltstone and thin beds of limestone, with a 4" bed of red shale at the bottom	Poor infiltration into heavy clay soils. Shale layer appears to be an effective barrier to downward percolation.
		50	Middle Unit - Bedded limestone and dolomite with lenses of chert	Moderately permeable.
		40	Lower Unit - Sandstone	Permeable and with sufficient porosity to offer some storage capacity.
Paleosol	?	0 - 5	Red clay soil that formed on top of the Madison Formation prior to the deposition of the Minnelusa Formation	Low permeability but irregular thickness. Thought to be the cause of small springs elsewhere in Black Hills, but of minor importance in monument.
Madison Formation (Pahasapa Limestone)	Mississippian	460	Massive limestone and dolomite, with some cherty layers	Major regional aquifer where it occurs at depth. Well drained in the monument. Low primary permeability, but greatly enhanced by solution cavities.
Englewood Formation	Devonian	40	Limestone, finely crystalline	Low porosity.
Unnamed Sandstone	?	10	Sandstone, medium to coarse	High porosity. This is the most important aquifer for the water supply wells.
Deadwood Formation	Cambrian	180	Limestone, dolomite and sandstone	Little or no porosity.
Precambrian Core	> 600 Million	Indefinite	Granite, granite pegmatite with lesser amounts of slate, schist, phillite and quartzite	Relatively impermeable.

Dyer (1961) suggested that these faults could capture and divert groundwater westward into the alluvium of Hell Canyon. If this process does occur, it does not saturate the alluvium into the rooting zone since the vegetation in the

bottom of Hell Canyon does not show a change in species or vigor which would indicate additional moisture. The amount of water may be insufficient or, with the strata dipping to the southwest, any alluvial water may have the

opportunity to rapidly reenter the carbonate aquifer.

### *Formation of Jewel Cave*

The formation of Jewel Cave and the role played by local and regional groundwater is discussed in some detail by Palmer (1984) and Bakalowicz et al. (1987). Their concepts are only briefly summarized here. The first cave development in the Madison Formation occurred relatively soon after its deposition, 320-350 million years ago. Most of the caves were filled with sediment as the Minnelusa Formation was deposited. After the initial uplift of the Black Hills 60-70 million years ago, the upper layers of sedimentary rock were eroded away allowing substantial amounts of water to enter the Madison Formation. The passages of Jewel Cave were formed by dissolution of the limestone around a network of fractures 40-60 million years ago. This event occurred when the cave was completely filled with water. The mechanism for dissolving the limestone is thought to be either circulating waters rich with organic acids, or possibly hydrogen sulfide rising in hydrothermal circulations from below the cave.

Once formed, the passages of Jewel Cave drained and were subject to weathering. Debris weathered off of the walls was deposited in the lower passages, filling some of them. The passages were again flooded for about 10 million years as sediments covered the lower slopes of the Black Hills and raised the regional water table. During this period the extensive calcite spar was deposited on the walls of the cave. As the sediments

were removed and the Black Hills underwent another period of uplift, the cave slowly drained and the groundwater circulation became established much as it is today. Water levels apparently rose and fell several times, flooding the lower parts of the cave.

Today, the water table is about 50 feet below most of the known cave. It is expected that the cave will intercept the groundwater table as more passages are discovered. Following the current dip of the Madison Formation, the lowest passages of the cave should intersect the groundwater table if they continue one-half to one-fourth of a mile further to the south.

### **Climate**

Meteorological records from Custer, South Dakota provide the best indication of climatic conditions at Jewel Cave. Average precipitation and temperature conditions for the period 1931 to 1952 are shown in Table 2. Custer is located about 12 miles east of the monument and at the same elevation. While the setting is similar, significant differences may occur because the valley that Custer sits in could experience more cold air drainage and lower nighttime temperatures than the monument, and precipitation patterns may vary slightly because the monument has a more southwesterly exposure. Day-to-day precipitation patterns vary due to localized storm events caused by orographic effects of the Black Hills. Meteorological data have been collected at Jewel Cave in recent years, but the period of record is too short to provide a good indication of long-term patterns.



Table 2. Precipitation and temperature summary for Custer, South Dakota, 1931-1952.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN.
PRECIPITATION (Inches)													
Mean Precipitation	0.39	0.51	0.88	1.86	3.14	3.51	2.85	2.05	1.15	.72	.53	.46	18.15
Mean Snowfall	6.0	6.0	10.4	5.7	1.6	0.2	0	0.1	0.5	2.5	4.5	6.2	43.7
TEMPERATURES (°F)													
Mean Min.	6.3	8.8	13.0	26.3	34.4	42.2	48.3	46.7	36.7	27.6	16.5	8.3	26.3
Lowest	-36	-27	-25	-2	10	19	30	30	15	8	-25	-26	-36
Mean Max.	36.4	37.9	40.0	53.7	60.3	68.8	79.4	78.9	68.3	59.4	44.9	36.7	55.4
Highest	56	64	72	78	85	89	97	94	91	82	71	62	97
Mean Annual Precipitation = 18.15"													
Standard Deviation is 3.62"													
High = 1947 (24.8")													
Low = 1936 (7.13")													

There is relatively little variation in the 20-year record for Custer, while Rapid City, with a longer record, shows much more variability (Orr 1959). This difference may be a result of the shorter record at Custer, or that precipitation at Rapid City, located on the edge of the plains, is in much more of a hit-or-miss situation than at higher elevations.

Average annual precipitation at Custer is 18.15 inches. There is a distinct maximum in spring and early summer, a minimum in the winter. Much of the winter precipitation falls as snow. Snow has occurred in every month of the year except July. Temperatures are cold in the winter, though often warmer than on the adjacent plains. Summers are cool.

## Topography, Soils and Vegetation

Land in the vicinity of Jewel Cave and in the Hell Canyon watershed is well dissected, with little flat land. The

elevation of ridges and streambeds gradually inclines to the northeast, with no large topographic breaks. The entire watershed is intricately divided by Hell Canyon and its tributaries, into a profusion of hills, slopes, and canyons. Elevation differences between the ridges and valleys is generally 200 to 300 feet, with Hell Canyon incised to 400 feet within the monument. Slopes average 20 to 40 percent.

Bear Mountain is the highest point on the Hell Canyon Watershed at 7,166 feet. From there the drainages of Bear Spring Creek and Hell Canyon descend over 2,000 feet to the confluence with Lithograph Canyon at 5,100 feet. The deep canyons include many entrenched meanders, requiring about 19 miles to traverse a watershed which is 12 miles long. Within the canyon bottoms there is very little channel meandering. The mean channel gradient is 105 feet/mile.

Plant and litter cover on the soil appears good in and near the monument, at least

for a semi-arid environment. As a result, erosion rates appear to be relatively low in spite of the steep slopes. The only accelerated erosion problems noted are associated with runoff from roads, parking lots, and to a lesser extent, buildings.

Much of the Black Hills has a forest canopy of ponderosa pine. This open forest and understory of grasses and shrubs is very effective at intercepting and transpiring precipitation. Rahn and Gries (1973) calculated that of the approximately 17 inches of precipitation in the southern Black Hills, 16.4 inches is lost to evapotranspiration, leaving only 0.61 inches of recharge to groundwater. They found that in the wetter northern Black Hills, average annual precipitation of 22 inches contributed 6.8 inches to recharge, while 15.2 inches are lost to evapotranspiration. These figures are based on a water budget where precipitation, streamflow and spring discharge were measured. Inaccuracies may be caused by unmeasured spring discharges, contributions to regional aquifers, and inaccuracies in calculating average precipitation.

With evapotranspiration removing such a large portion of precipitation from the ground and surface water systems, vegetation management could have a considerable effect. Forest practices including stand-thinning, harvesting, conversion to grasses, and fire management could affect water yield over the watershed, while developments in the monument could increase water yield, locally.

## Surface Hydrology

### *Surface Waters*

The limestone geology around the Black Hills supports extensive areas of karst, where solution cavities produce disappearing streams and sinkholes. No perennial streams exist in the vicinity of the monument due to relatively scant rainfall, substantial evapotranspiration, and very porous rock substrate. Surface flow in Hell Canyon or any of the smaller drainage channels is rare, even after substantial rainfall of up to two inches in a 24-hour period.

The only perennial surface water sources are seven small springs or seeps located in or near the monument, which are listed in Table 3. These sources all appear to issue from local water tables perched above the shale layer in the middle of the Minnelusa Formation. This shale acts as a barrier to downward percolation of groundwater, forcing it to move laterally until a more permeable zone allows the downward seepage to continue, or till it reaches the surface as a spring.

These are similar to "type 5" springs, as described by Rahn and Gries (1973), where small seeps apparently result from local groundwater pooling on top of the paleosol which caps the Madison Formation. Here the shale layer in the Minnelusa Formation is the most restrictive layer, while the paleosol has little or no effect on the water. The barrier to downward percolation offered by the shale is neither perfect nor extensive enough to capture large amounts of groundwater, or carry it



great distances, so all of these springs are very small, discharging less than 5 gallons per minute (gpm). Surface discharge has been reported at Prairie Dog, Lithograph, Chokecherry, Upper Stockade, Lower Stockade, and Log Trough Springs, though no accurate discharge measurements have been made.

Several other springs are scattered further north in the Hell Canyon watershed, and there is at least one resident stock pond. Flow characteristics and developments for these springs are not known, though they are thought to be small, and several have probably been developed as water sources for several ranches.

Jewel Cave Spring was the sole potable water supply for the monument until 1961 when it was replaced by the well which is still in use. This source yielded about 2 gpm in the summer. When the spring was visited in August 1991, there was no water visible at the surface outside of the collection tank, but it continues to provide water to a faucet at the old headquarters.

Dyer (1961) describes an unnamed spring in Hell Canyon which was developed for a CCC camp but was nearly dry when he visited in May 1959. Two spring developments were found on recent visits to this spring; one spring tank with a small amount of water, and a dry cistern. Of the small springs around the monument, this is the only one which definitely issues from below the Minnelusa/Madison Formation contact. This spring could originate at the unnamed sandstone that provides the aquifer for the monument's well, which

should be near the elevation of the bed of Hell Canyon north of the Jewel Cave Fault.

There is at least some reason to doubt that Hell Canyon was ever a perennial stream through the monument, in recent geologic time. The canyon bottom is cut into the Madison Formation where porosity is greatly enhanced by fractures and solution cavities. Many streams in the Black Hills lose substantial amounts of water to the solution cavities in this formation. It is unlikely that a perennial stream could flow through this area unless the local water table was high enough to inundate most of Jewel Cave, which is situated below the level of the streambed. Riparian vegetation is not apparent in the bottom of Hell Canyon indicating that additional water is not regularly available near the surface. Ponderosa pines, some approximately 300 years old grow on the low terraces in Hell Canyon, yet this species is intolerant of saturated soil (USDI, Fish and Wildlife Service 1988).

If there has been a reduction in flow in Hell Canyon, several possible explanations can be offered, none of which have as yet, been investigated.

- Successful efforts to suppress wildfires may have resulted in denser vegetation and increased water loss to evapotranspiration.
- Long-term trends in the amount or seasonality of precipitation may have lead to less runoff. There is an apparent trend toward drier conditions in the Black Hills with numerous stock ponds and spring

Table 3. Springs in the vicinity of Jewel Cave National Monument. Springs marked with an (\*) are in close proximity to the monument, but outside the boundary.

SPRING NAME	LOCATION <sup>1</sup>
Prairie Dog Spring	D(4-2)2 dcb
Lithograph Spring *	D(4-3)6 bdc
Chokecherry Spring	D(4-2)12 bad
Jewel Cave (Headquarters) Spring	D(4-2)2 aab
Upper Stockade Spring *	D(4-2)12 ada
Lower Stockade Spring *	D(4-3)7 bbc
Log Trough Spring *	D(4-2)12 add
Unnamed Spring in Hell Canyon *	D(3-2)35 abd

<sup>1</sup> Location is described in Township and Range in a notation where quadrants of the compass are represented by A = Northeast, B = Northwest, C = Southwest, and D = Southeast. For example D(4-3)6 bdc describes a spring in the Township 4 S, Range 3 E, Section 6, southwest quarter, of the southeast quarter, of the northwest quarter.

developments which are currently dry (though this may be more indicative of overly optimistic water development than climatic trends).

- There are several ranches in the watershed above the monument where spring developments, stockponds, and wells, may be reducing flows downstream.

## Flooding

Hell and Lithograph canyons are subject to occasional floods, though none have actually been recorded by monument staff. Both canyons are steep-walled with relatively narrow canyon floors. The active channel occupies a large portion of the bottom of Lithograph Canyon, while a floodplain of low terraces exists in Hell Canyon. With the exception of service roads, no monument developments or facilities are located in the drainage bottoms. No

other areas of the monument are subject to flooding.

Some idea of the potential for flooding can be gained by examining the Rapid City flood of June 9-10, 1972 (Schwarz et al. 1975). Over 10 inches of rain fell in six hours over a 60 square-mile area on the east slopes of the Black Hills. Two-thirds of the streams included in the study experienced flows in excess of a 50-year event. If major storms like this occur upstream of the monument, they would cause very significant flooding in Hell and Lithograph canyons. Runoff from the 1972 Rapid City storm ranged from 400-700 cubic feet per second per square mile (cfs/mi<sup>2</sup>) of watershed. Assuming even half the runoff rate for the Hell and Lithograph canyons' watersheds, because they contains more sedimentary rock and deeper soils, a similar storm event would produce flows of 11,000-19,000 cfs and 600-1,100 cfs, respectively. Such a flood,



while spectacular, would not threaten any monument facilities except dirt roads.

Monument staff, with 10-12 years of observation, note that storms over this period have never been seen to produce surface flows in the large canyons, even after storm events recording five inches of rain in two days. This lack of flooding could be a result of few truly large storms during this period, or the large infiltration capacity of the watershed and channels. Lithograph and Hell canyons do contain channels so periodic flows must occur, though apparently only after very large precipitation events.

## Surface Facilities and Activities

### *Monument Facilities*

All of the monument's administrative support facilities are located on lands which overlay known cave passages (see Figure 1). These include the visitor center, parking lot, maintenance yard, employee housing (consisting of three single family units, a four-plex, and three mobile homes), a 100,000-gallon water storage tank, the old headquarters building, sewage lagoons, and access roads. Leaks in the wastewater system have impacted the cave and are discussed in some detail, below. Other potential threats include road and parking lot runoff, and fuel spills or leaks. Alterations in surface water runoff and/or infiltration could change flow characteristics in the cave.

One of the underground fuel storage tanks in the monument was discovered

to be leaking in 1976 and was replaced. In 1989, when all of the tanks were replaced with double-walled tanks which meet current standards, about 90 cubic yards (yds<sup>3</sup>) of contaminated soil was discovered and removed. There are currently three 1,000-gallon, and one 4,000-gallon underground storage tanks in the monument which are now monitored regularly for leaks in accordance with "NPS Guidelines for the Management of Storage Tanks."

Another surface development of concern is U.S. Highway 16 which passes along the western boundary and through the monument for 2.5 miles. This is the major east-west highway running through the southern part of Black Hills. It is a two lane road which is generally wide and straight, except for the section of the road through the monument. Here the road is narrow and winding, containing steep grades as it descends into Hell Canyon. Accidents are common as drivers fail to appreciate the sharp curves. The highway passes directly over known cave passages, particularly west of the monument.

This highway was once a major transportation route for fuel trucks, but the number of fuel trucks has greatly diminished in recent years. Accidents still occur regularly, but fuel spills are usually confined to the relatively small operating tanks on the trucks. The monument provides emergency medical response to this stretch of highway, and now has the capability to respond with containment and cleanup equipment.

The state is considering three alternatives to correct some of the problems with

this section of U.S. Highway 16: (1) widening along the existing alignment, (2) constructing a new road and bridge to the north of the Jewel Cave Fault but still in the monument, and (3) constructing an alignment further north, completely outside the monument. Of these, the second would offer the greatest reduction of threats to the cave. Being north of the fault would offer some separation between the road and cave, and its location along the ridge would minimize the need for road salting. The third alternative, though further from the cave, would have a north exposure and require substantially more salt in winter. Widening at the existing alignment does little to reduce threats to monument resources. Construction on this project was imminent, but has been pushed back several years due to a shortage of funds.

Improved road alignment should greatly reduce, but not eliminate, the risk of spills and contamination reaching the cave. The road will rejoin the existing alignment very near the westernmost extension of known cave passage.

### *Potential Sources of Contamination in the Watershed*

Activities in the watershed outside the monument may be affecting water resources in the cave and there is a potential for future impacts. Recent analyses have detected traces of Tordon in the cave. This herbicide is used by the U.S. Forest Service for vegetation treatment in the watershed.

There are at least seven small ranches in the 55-square miles of watershed above

the monument, the nearest is approximately 10 miles upstream. Bacterial contamination is possible from human and animal waste. There is also a potential for contamination from petroleum products and agricultural chemicals, though the volumes consumed are suspected to be small. Activities and developments on the groundwater drainage basin are limited to a similar number and density of small ranches.

There are several other ranches located on privately owned lands east and southeast of the monument. Surface drainage from these ranches is south into Layton Canyon, which drains south-eastward into Pleasant Valley. The current limits of cave exploration has mapped passages to within a quarter-mile of the nearest ranch, and undiscovered passages could potentially extend much farther. Potential impacts from these ranches include contaminants leaching into the groundwater, changes in hydrology from vegetation modifications, and surface disturbances. Changes that alter the permeability of soils or impermeable rock layers could have a profound effect on the location and volume of water entering the groundwater system.

Active mining in the watershed appears to be limited to some small quarries for limestone and aggregate. The Madison Formation has been identified as a source of rock aggregate while the Minnelusa Formation is not considered useful (Dersch and Wiles 1989). A U.S. Forest Service quarry is located in the Hell Canyon watershed about six miles north of the monument. The potential



for impacts from this quarry to the monument are very limited, particularly at this distance. Though new quarries could be constructed nearer the monument, with a potential to disturb local surface water hydrology and contribute sediment laden runoff, none are planned and the existing ones have very large reserves.

Even though there are 394 mining claims on land withdrawn from mineral entry surrounding the monument, the potential for impacts from mining locatable minerals appears to be low. This is because the extensive limestone formations in the area show little evidence of mineralization. Some exploration has occurred for uranium in the Deadwood Formation, east of the monument. The success of these efforts is not known, nor is it known if exploration or mining in this formation can affect the hydrology of the cave in the overlying Madison Formation. The only other exploratory work done on any of the claims around the monument is some small scale removal of aggregate (USDA-FS 1989).

## Groundwater Hydrology

### *Unsaturated Groundwater Flow*

Jewel Cave is only 150-300 feet below the ground surface and is entirely in the unsaturated, or vadose zone (Alexander et al. 1986). With the possible exception of yet-to-be explored passages to the south, the entire cave lies above regional or local water tables.

In general, movement of groundwater in the vadose zone is downward under the influence of gravity, but specific flows can be variable and extremely complex, even under relatively constant conditions. The speed and direction of flow are affected by the amount and timing of water supplied, the attraction of water to soil and rock particles and pore spaces, the availability of fractures or other large channels, and the presence of layers of differing permeability. As a result, water falling on the surface can arrive in the cave as relatively constant seepage, as multiple pulses, or as some even more complex pattern. Vadose flow (in fractures) appears to predominate over vadose seepage (in pore spaces and minute fractures) in Jewel Cave.

Pore spaces in the vadose zone have the ability to hold some water indefinitely against the force of gravity. Additional water added to the system will move downward until it encounters a perched water table or ultimately, the regional water table. Once under saturated conditions, groundwater flow will be determined by the hydraulic gradient and the character of the media.

Wiles (1992) investigated the location and volume of water flow in the cave. The location of wet areas in the cave are depicted in Figure 2. Three different dripping rates (high, medium and low) were identified along with three hydrologic zones in the cave (little or no drips, perennial drips, and seasonal drips). Dry areas of the cave were identified under the caps of Minnelusa Formation, where downward percolation is effectively blocked by the upper unit





Figure 2

**WET AREAS IN JEWEL CAVE**

**JEWEL CAVE NATIONAL MONUMENT**

United States Department of the Interior • National Park Service

DSC • May 94 • 146 • 20015



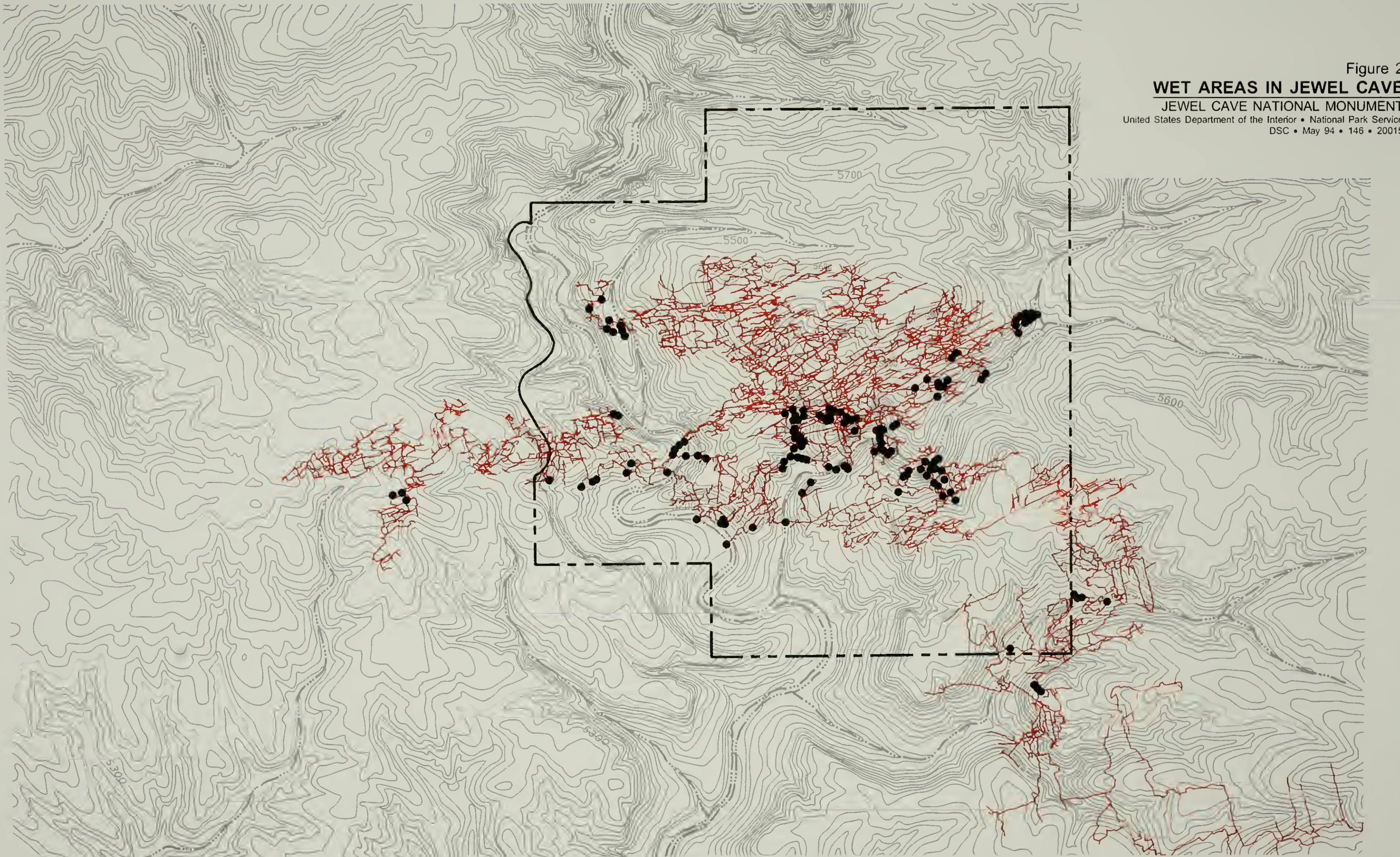


Figure 2

**WET AREAS IN JEWEL CAVE**

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of the Minnelusa Formation and its lower bed of red shale. Permanent drips are found under the lower layers of the Minnelusa Formation where the impermeable layers have been removed by erosion. There is apparently sufficient storage capacity here to support perennial drips, which exhibit a relatively constant base flow, then respond to precipitation events once the storage needs have been satisfied. Seasonal or short-term drips occur beneath drainage bottoms where the Minnelusa Formation has been removed and water can easily infiltrate and percolate, but where there is little storage capacity.

Downward flow and infiltration is more effectively blocked by the upper sandstone unit and red shale layer in the Minnelusa Formation than by the paleosol at the Minnelusa-Madison contact. The paleosol appears to be an imperfect aquatard and affects flow patterns only locally. Most of the small springs in and near the monument issue from the base of the upper unit of the Minnelusa Formation then infiltrate again a short distance below. This is further indication that the red shale layer is an effective barrier and that water is being displaced away from the thickest portions of the Minnelusa Formation, supplementing the more numerous wet areas underlying the lower slopes.

Drip rates measured by Wiles (1992) showed that considerable precipitation and snowmelt must occur in the spring before drips begin responding with higher flows. Thereafter, drip rates can respond within two days to heavy

precipitation, and fall to a base level within about a week. Drip rates did not show a simple relationship to normal precipitation events (i.e., they did not respond to every storm event).

When volumes of flow were extrapolated to include all wet areas under a small drainage basin, flow in the cave accounted for only about one-fourth of the estimated flow that should be moving through the area, assuming 95% of precipitation is lost to evapotranspiration (ET). Accountability increases to one-half of the estimated flow when a higher rate of ET is assumed for adjacent contributing areas.

Possible explanations offered for the unaccounted flow include: underestimation of the flow through the cave; a significant amount of vadose flow moving around cave passages; underestimation of ET rate; and overestimation of water yield from the upper Minnelusa Formation. Underestimation of ET is a possibility because the study drainage is south facing so ET should be higher than average. Another possible explanation is that groundwater flow patterns are such that the groundwater drainage areas and surface watersheds do not coincide.

Flow through the unsaturated zone at Jewel Cave was first investigated by Alexander et al. (1986), and Alexander et al. (1989). The later investigation incorporated the findings of the first, and consisted of a three-year study examining water quality and occurrence in Wind and Jewel caves, and human impacts to the natural hydrologic system.

Three dye tracer studies were conducted by Alexander et al. (1989). The first dye tracer analysis was conducted in 1985 in order to detect pathways from the sewage system to waters in the cave. On September 15, 1985, Rhodamine WT dye was flushed down several toilets. Transmission was so direct that the researchers observed, "the first pulse reached the New Wet Area-East *before* the bulk of the dye reached the monument's sewage lagoon" (emphasis added). Random pulses were also detected at two of the other three sample locations several weeks following the dye introduction, and continued to the end of the sampling period (220 days after injection).

Two subsequent dye traces investigated possible connections between parking lot runoff and the cave. Dye was flushed out of the parking lot with simulated storm events on August 23, 1986, and July 14, 1987. In the first trace, dye was recovered at two of 12 sample points, with the first recovery within two weeks. Both positive sample sites were 200 to 300 vertical-feet below the surface, almost directly under the release point. Dye from the second trace was detected in the cave 8-10 days after release. At one site, it was recovered at higher levels one year later, than in the first several days and weeks following release.

The researchers concluded:

1. dye in appeared to move as random pulses not as conduit flow nor as simple diffuse flow;

2. pulses may move horizontally as well as vertically;
3. flow patterns under these situations are not well understood and difficult to predict; and
4. monitoring in this environment will require both frequent (daily to hourly) and long-term (months to years) sampling.

As a follow-up, samples were collected from two of the dye monitoring sites and analyzed for fecal coliform bacteria, but none were detected. This might indicate that the bacteria were being filtered out by the overlying rock and soil; that the wastewater was making up a very small portion of the cave drips; or that bacteria also move in random pulses which one-time sampling did not capture.

Wet areas, in the form of drips, pools and sheet flow, are not evenly distributed in Jewel Cave. As shown in Figure 2, they are found in scattered areas of the cave, mostly adjacent to the large drainages of Lithograph and Hell canyons. The same mechanism responsible for the small springs in and around the monument appears to be a major factor controlling the occurrence of wet areas in the cave. Water moves laterally toward the canyons, either through the soil or shallow rocks, or on the shale layer in the middle Minnelusa Formation. Once it reaches an area where the shale has been eroded away or is locally more permeable, water is free to (percolate) generally downward into and through the cave. Wiles (1992) found that the volume of water dripping



in the cave seemed to correlate with the size of the surface watershed above that point, however, a dye trace designed to confirm this has produced only negative results.

Water movement might also be influenced by the paleosol between the Minnelusa Formation and the Madison Formation. Though Rahn and Gries (1973) identified the paleosol as a restrictive layer that produces small springs which they described as "type 5," elsewhere in the Black Hills, it does not appear to be a significant factor in this area. None of the small springs near the monument issue from the level of the paleosol outcrop.

Another possible explanation for the location of wet areas in the cave is water moving laterally through the modern soil. Lateral water movement through the soil has not been documented, though it may have been observed in a construction pit dug in the drainage west of the visitors center. Water moving through the root zone is subject to evapotranspiration, concentrating most of the dissolved minerals. If this is occurring, it could explain some of the difference between drip-water chemistry in Jewel and Wind caves as attributable to differences in vegetation.

Investigations into surface and groundwater circulation are currently continuing on a limited basis, as part of the water quality monitoring program. Dye traces are being used for quantitative and qualitative comparisons of water movements in and through drainages. The objective of this work is to determine how long it takes water to

move from a surface drainage to the cave, if groundwater movements are influenced more by near-surface conditions (soil and topography) or by stratigraphy, and if the small springs in the area are intimately associated with cave water.

### *Regional Groundwater Circulation*

An understanding of the general groundwater circulation in the Black Hills is provided by Rahn and Gries (1973) and Rahn (1975). Though these papers are somewhat dated, they represent the current state of knowledge in this area.

Groundwater supports several springs located in and along the margins of the Black Hills, and may also contribute to the artesian basins situated on the plains. The potentiometric surface dips gradually away from the center of the uplift. Groundwater movement and spring location are controlled by the relative permeability of the bedrock units listed below, from top to bottom. Layers present and affecting groundwater movements in the vicinity of the monument are indicated by an asterisk.

**Cretaceous Aquitard.** Cretaceous black shales.

**Sandstone Aquifer.** Cretaceous and Jurassic sandstones and interbedded shales.

- \* **Triassic-Jurassic Aquatard.** Spearfish Formation and Sundance Formation.
- \* **Carbonate Aquifer.** Minnelusa Formation and Madison Formation.

- \* **Precambrian Aquitard.** Winnipeg and Deadwood formations, and underlying Precambrian metamorphics.

Precambrian rocks exposed at the center of the Black Hills uplift are for the most part, impermeable. There is little infiltration or groundwater movement; springs are generally small, and water moves predominantly via surface flow in streams.

As streams cross the Madison Formation substantial amounts of water are lost through sinkholes and porous streambeds to the carbonate aquifer. Rahn and Gries (1973) estimated the loss to be 44 cfs for all streams in the Black Hills.

Several large springs occur around the base of the Black Hills where further movement of the groundwater is blocked by the overlying Spearfish Formation. Groundwater is either forced to the surface here, or enters into the regional aquifer and out under the plains. The combined discharge of these springs is about 190 cfs. Water entering the aquifer as precipitation directly onto the limestone apparently makes up an additional 146 cfs, and contributes to the unquantified recharge to the deep regional aquifer. The rate of recharge from precipitation was estimated to be at least 6.8 inches/year in the northern hills, diminishing to at least 0.6 inches/year in the southern hills, with the difference attributable primarily to differences in precipitation.

Dye traces have demonstrated that the water entering the carbonate aquifer can

reemerge in the same stream, or in entirely different drainages. In some cases, it appears that several streams might be interconnected with the water moving relatively freely between them through the karstic limestone (Rahn and Gries 1973).

Regional groundwater flow through the Madison Formation in the vicinity of Jewel Cave is inferred to be to the south-southeast towards Cascade Spring, 30 miles away. Cascade Spring is thought to drain the southwestern quarter of the Black Hills and discharges 20 to 25 cfs. Jewel Cave is near the divide between flow to Cascade Spring and to Stockade Beaver Creek, 12 miles to the west (Rahn and Gries 1973). The exact location of the divide is not known. Since Jewel Cave is near the divide, and is located in a relatively dry portion of the Black Hills, the subsurface flow system is probably not well developed nor transmitting large amounts of water. This situation has significance for the monument in three ways:

1. The small volume of available water makes it unlikely that the monument or other landowners will be able to sustain large amounts of groundwater pumping. This lowers the potential for large developments in the area if the long-term water supply is considered.
2. There is little opportunity for contamination of the aquifer above the monument due to the relatively small amount of land draining to the



monument, and the generally undeveloped nature of the drainage basin.

3. If the aquifer is tapped, the monument's water supply well could be vulnerable. For this reason, it is important that records of pumping and water levels be maintained.

Even though the regional circulation of groundwater can be inferred with some degree of certainty, local circulation patterns remain unknown. The sewage lagoons might be up-gradient of the monument well, even though they are located to the south and down-gradient, in a regional sense. Local groundwater flow toward the well is made more likely because the cone of depression caused by pumping draws water toward the well.

Activities in or near the monument which contaminate local groundwater can also lead to contamination of the regional groundwater system. This situation could adversely affect water users down-gradient.

## Water Quality

### *Water Quality Standards*

Neither surface or groundwater regulations in South Dakota establish specific standards for cave waters. Regular surface and groundwater regulations will provide some protection, and the provision for outstanding resource waters designation appears to be very useful.

As in other states, surface water quality is protected through the establishment of standards based on the protected uses, but these are not established for Hell Canyon because it is an ephemeral stream. Rather, "All streams in South Dakota are assigned the beneficial uses of irrigation, and wildlife propagation and stock watering" (State of South Dakota, Uses Assigned to Streams, § 74:03:04:01). In a practical sense, application of these standards in the monument is difficult due to the scarcity of flow, and the fact that criteria under these uses are the least stringent among designated uses.

A far more valuable standard is for outstanding resource waters (State of South Dakota, Uses Assigned to Streams, § 74:03:02:54). This allows the designation of site specific criteria to protect or maintain the integrity of waters "that are of high quality or are of exceptional recreational or ecological significance." To achieve an outstanding resource waters designation, a proposal must be made to the state Water Management Board demonstrating the outstanding nature of the water resource. Application of an outstanding resource waters designation to Jewel Cave would be the first use of this designation for cave waters in the state. The national significance of the resource fits the designation very well.

It is not necessary to propose specific water quality criteria at the time of an outstanding resource waters proposal, but development of such criteria will be needed for effective enforcement. Building a database adequate to characterize the desired water quality conditions should be a consideration in

designing the water quality monitoring program.

The quality of groundwater in South Dakota is protected statewide by one designated use: drinking water. Unfortunately, the state defines groundwater as "water below the land surface that is in the zone of saturation," so none of the drip water in the cave would be included (State of South Dakota Groundwater Quality Standards 74:03:15). The monument's well, and waters discovered in the future where the cave intersects the water table will be afforded some protection. Even though this establishes fairly high standards, there could be changes from natural conditions before the standards are exceeded. Regulations also exist for the discharge of wastewater to groundwater and spill cleanup.

### *Past Water Quality Investigations*

Prior to investigations by Alexander et al. (1989), the only information about chemical characteristics of water in Jewel Cave were the analyses of the water supply well. These analyses provided little information about the waters of the cave because it was obtained from the saturated zone in lower strata, not the unsaturated flow that passes through the cave. The investigators initiated a three-year study in 1985 containing objectives to:

- (1) evaluate the water distribution within Jewel and Wind caves,
- (2) determine the effects of human impact upon the natural hydrologic system, (3) document any detrimental effects to the

water quality, (4) document any instances in which the cave environment is adversely affected by the quality or quantity of water present, (5) provide options to change present water use or management practices, if necessary.

Waters of Jewel Cave were generally found to be dominated by calcium, magnesium and bicarbonate, as would be expected in a karstic dolomitic limestone. The investigators were mildly surprised to find that samples from Jewel Cave were much more magnesium-rich than waters in Wind Cave. Calcium magnesium ratios (Ca/Mg) in Jewel Cave varied from less than 0.5 to greater than 4, but only samples from pools and wells had a Ca/Mg ratio of more than 1.0. Subsurface waters from Wind Cave had Ca/Mg ratios much closer to 1.0, even though it is located in a similar geologic and topographic setting. It was suggested that the elevated magnesium is a result of greater evapotranspiration from forested lands over Jewel Cave, in contrast with grasslands over Wind Cave.

Nitrate was examined as a possible indicator of sewage contamination. Concentrations were measured at generally less than 1 part per million (ppm). Exceptions were the pools below the unlined sewage lagoons which had 3.6 to 6.2 ppm in June 1985. The lagoons were lined in the summer of 1985. The pools had not dried up when the area was revisited in 1988, but nitrate concentrations had declined from 5.83 ppm to 3.54 ppm. The improvement is encouraging, but it is



difficult to demonstrate a clear trend based on only two samples. Nitrate concentrations measured between 1 and 3 ppm at several other sample sites, which could be the result of continued or residual contamination, or represent natural background in this area.

Chloride concentrations were variable. A trimodal distribution shows a large group of samples with very low concentrations, another large group of samples with low to moderate concentrations (20-40 ppm), and a small number of samples with relatively high concentrations (as high as 200 ppm in the Dungeon Room). Those samples with greater than 10 ppm were interpreted as indicators of contamination. Most of the elevated samples were collected in the vicinity of the tourist trails, and from sites down-slope from the highway including samples taken in the historic tour section, and on the surface at Prairie Dog Spring. Sodium concentrations were less variable than chloride, and elevated in most of the same locations.

Sulfate levels were distinctly bimodal with concentrations consistently less than 35 ppm except in the vicinity of the tour trail where concentrations were between 50 and 106 ppm. The source of the elevated sulfate was not clear. It may be a natural anomaly or the result of contamination from tours, surface developments, or subsurface developments.

An analysis from the drinking-water well revealed no synthetic organic compounds in excess of the limits of detection. While this is a good sign, it is

based on a single sample and does not rule out hydrocarbon contamination in the cave. Some evidence of parking lot runoff was detected in Wind Cave, where the parking lot also sits above the cave.

### *Current Water Quality Investigations*

The monument is currently in the second year of a two-year effort to design a long-term water quality monitoring program. Assistance is being received from the NPS Water Resources Division, state of South Dakota, and U.S. Environmental Protection Agency (EPA). The purpose is to identify the existence and sources of water pollution and to develop a study design for a long-term monitoring program which should be funded from the monument base. Program design will focus on identification of sample sites, parameters and techniques suitable for documenting sources of contamination such as parking lot runoff, sewage leaks, and road salting.

EPA has provided an evaluation of the monitoring program, laboratory analysis, and assistance in evaluating results. Investigations in Jewel Cave provides EPA with an opportunity to investigate the connection between surface activities and subsurface water quality, which would have applicability to mine drainage problems they are investigating elsewhere in the Black Hills. The partnership with EPA also provides the monument with special expertise in the detection and evaluation of contaminants, and EPA's independence can facilitate contacts with other

agencies to investigate of sources contamination.

Initial recommendations from EPA included measures to improve sampling techniques and laboratory analysis, which greatly lowered the limits of detectibility for the parameters of concern. This activity was followed by two years of sampling in an effort to build a representative database. Preliminary results include the detection of pesticides and parking lot contaminants such as metals, oil and grease, xylene, toluene and benzene. Further analysis of the data is needed in order to determine the significance of these results, and the monitoring program may be modified in order to better identify sources and pathways of contamination.

The state of South Dakota is also supporting the water quality monitoring program. They are interested in identifying the nature of unpolluted waters in the Black Hills, and investigating the source of elevated levels of lead found in samples from Jewel and Wind caves. In January 1992, waters from throughout both caves (including the lakes) were found to have elevated levels of metals including lead (up to 276 parts per billion [ppb]), zinc, copper, chromium and nickel. These high levels have not persisted in subsequent samples, so there may have been some sample handling or analysis error. If the analysis is accurate, the presence of these metals in high concentrations is thought to be a natural occurrence because it is so widespread in both cave systems. Two possible origins are sediment pockets in the upper reaches of the

Madison limestone, which were also found to contain high concentrations of metals, arsenic and thallium; or manganese deposits in the cave.

Temperature is measured on site, pH and conductivity are measured as soon as samples are transported out of the cave. Separate samples are collected for nutrient analysis and samples are preserved with nitric acid where appropriate.

### *Logistics of Water Sampling*

The difficulties involved in collecting samples in Jewel Cave limits the number of sample sites and samples that can be collected; or greatly increases sampling costs. Several hours of arduous travel is necessary to reach many wet areas of the cave. Cave water sampling is also more difficult than sampling surface waters, because water is not found in convenient pools or streams. Most of the water in Jewel Cave occurs as drips or sheet flow on nearly vertical surfaces, and some of the drips are so slow that it takes several hours to fill a sample bottle. Monument staff have developed an innovative sampling technique involving a tarp to collect drips and tubing feeding water to a sample bottle.

### *Water Supply*

Jewel Cave Spring provided the potable water supply for the monument until 1961 when it was replaced by Well #1 which is still in use. Developments at the spring included a 3'x 3'x 6' concrete collection box, and 1,200 feet of pipe carrying water to a 3,000-gallon concrete reservoir at the headquarters. It yielded



about 2 gpm in the summer with annual consumption of about 150,000 gallons/year. This low flow proved inadequate to meet demand so a groundwater supply was sought (NPS Master Plan 1964).

Water for the monument is currently obtained from two wells, the first drilled to 700 feet as a test well in August 1959, the second drilled in 1984 to a depth of 810 feet. The wells are located in quadrants D(4-2)2 adb, and D(4-2)2 aca, respectively. Both wells penetrate all of the overlying sedimentary strata and bottom in the Precambrian metamorphic basement rocks.

Drilling of the first well and its' hydrology are discussed in some detail by Dyer (1961). Water was produced mostly from an unnamed 10-foot thick layer of white sandstone between the Englewood Limestone and the Deadwood Formation. This layer is not known to be extensive in the area, and not known to be a major aquifer. Other zones of saturated sandstone were penetrated in the lower Deadwood Formation, but these produced less water. All other rocks penetrated were either unsaturated or of low permeability, and provided little water.

At the time of drilling, the static water level in Well #1 was 390 feet below the surface (water surface at 5,340 mean sea level [msl]). Pumping at 14 gpm for 70 minutes resulted in a drawdown of 110 feet. Recovery required about 20 hours. Monument staff found that sustained pumping at 10 gpm caused the water level to drop below the level of the pump. Pumping at 8 gpm was

sustainable. The well was cased with six-inch pipe, perforated opposite the schist and productive sandstone, and a cylinder pump installed.

The water supply proved to be inadequate in the 1980s following increases in visitation and staff, so a second well was drilled about 400 feet to the northwest. The new well is 810 feet deep with the pump set at 560 feet. Static water level at the time of drilling was 420 feet below the surface. This well intersected a zone of much higher production and was tested at up to 80 gpm with the water level stabilizing at 523 feet below the surface. When pumping was reduced from 70 gpm to 60 gpm, the water level rose 20 feet in 2.5 minutes. The well is currently pumped at 17 gpm in the summer, with the period of pumping reduced in the winter or shut down and replaced with pumping from Well #1.

While some drawdown tests have been conducted on the monument wells, long-term monitoring of static water levels has not been conducted. The empirical indication is that current levels of pumping can be sustained.

Water is pumped from the wells to a 100,000-gallon concrete reservoir located on the hill above the residences and visitors center. Consumption in 1991 was about 750,000 gallons.

Alexander et al. (1989), included a single sample analysis of the drinking water supply at Jewel Cave for isotopes of carbon and tritium, to determine its residence time in the ground, and synthetic organic compounds. The well

water was found to contain  $^{14}\text{C}$  levels and modern tritium, indicating it is either a mixture of pre-and post-1960 water, or it infiltrated near some time when atmospheric nuclear testing began.

## Wastewater Disposal

There are two wastewater systems in the monument. All facilities except the historic headquarters are on a centralized collection system with disposal to evaporative lagoons. The system appears to be working well now, but has a history of problems that have resulted in impacts to the cave. Sewer lines and the lagoons are located over the known cave, and may be up-gradient of the water supply well.

A two-cell sewage lagoon and a collection system were constructed in the 1960s, coinciding with construction of the new visitors center and residential area. A bentonite liner was installed, as was customary practice at the time, but this proved to be a relatively ineffective barrier. Most of the liquid waste rapidly infiltrated. The lagoons only filled to about 20% capacity in spite of inflows that far exceeded evaporation.

Suspensions were further aroused when some previously dry areas of the cave became wet after construction of the new facilities. That portion of the cave was called the "New Wet Area." Tom Aley, of the Ozark Underground Laboratory found optical brighteners (used in household detergents) in drip waters along the scenic trail in Jewel Cave in 1984 (Aley 1984). The collection system was also suspected of leaking. A television inspection of the

pipes in about 1984 showed numerous breaks and leaks. A dye-tracer study in 1985 (Alexander et al. 1989) demonstrated a nearly direct route of contamination into the cave. An area of rare cave velvet along what is now the scenic tour route was wetted by the excess water (Dersch and Wiles 1989). Gypsum and hydro-magnesite minerals in the cave were also at risk from changes in the moisture regime.

Synthetic liners were installed in two cells of the sewage lagoons in 1985, and the third cell rehabilitated and lined in 1987. Leaking sewer pipes were slip-lined in 1989. These actions increased the amount of wastewater stored in the lagoons to the point where the threat of overflow is a chronic problem. The lagoons reached capacity in 1990 and 100,000 gallons of wastewater had to be hauled to Newcastle for disposal. Water conservation measures were instituted throughout the monument the following year to reduce the amount of sewage effluent.

Several options are being considered to alleviate the long-term problem including enlarging the lagoon system to increase evaporation, and developing another system of disposal such as spray fields. Alternatives which include land application of effluent have been rejected due to concern for contamination of the underlying cave, and effects to natural vegetation. One concern for enlarging the lagoons is that they intercept precipitation which would normally contribute to the groundwater system, and to the cave below.



Installation of composting toilets for visitors which would not discharge into the sewage system is also being considered at the old headquarters. Prior to 1960, all monument facilities were located at the old headquarters near Hell Canyon. They were serviced by a 1,000-gallon septic tank leach field system located 1,500 feet south of the old headquarters, which was installed in 1963 before cave passages under Hell Canyon had been discovered. At this time, there are no known cave passages within 300 feet laterally of the septic tank. Further exploration may identify segments of the cave in this area because passages are known to exist in every direction. Conversely, new areas may not be found because passages in this area are absent for some reason, or are too small to be explored. Air movement from leads in this area is

much less than from other parts of the cave currently at the limits of exploration.

The old headquarters is now used as a seasonal residence part of the year, and provides public restrooms for the relatively few visitors participating in the historic cave tour. The septic tank is apparently functioning well, treating the small amount of wastewater that is generated. Whether the volume generated is sufficient to flow beyond the rooting zone and into the possible cave below, is not known. The Draft General Management Plan for the monument includes a proposal to replace this system with composting toilets or a hookup to the existing lagoons. Composting toilets or other zero-discharge systems are excellent for protecting shallow groundwater if they are used within the design capacity.

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## WATER RESOURCE ISSUES AND RECOMMENDATIONS

### General Recommendations

Significant water resource issues facing the monument and recommendations for addressing them are presented in this section. Where actions are recommended which will require additional funding or staff, project statements are provided in Appendix A. These can be inserted in the monument's Natural and Cultural Resource Management Plan.

The list of project statements and issues that need to be addressed would be much longer had not the monument staff been aggressive in investigating water quality problems in the past, and taking effective actions to correct them. Future investigations should proceed to develop a more thorough understanding of the hydrologic systems, document the more subtle impacts, and monitor conditions so that past problems do not recur.

Several of the proposed actions in the Draft General Management Plan (GMP)

address water resources issues. These include: replacing the septic tank and leach field with a self-contained system, establishing limits of acceptable change criteria for cave resources, redesigning the parking lot, and continued cooperation with the U.S. Forest Service to protect cave resources. Continued hydrologic investigations and monitoring are also proposed and will help determine the success or failure of the various actions. Should the proposed actions prove unsuccessful in preventing or mitigating cave impacts, the GMP should be reopened to explore other alternatives including relocation of facilities.

In evaluating many of the threats facing Jewel Cave, an important consideration is that more cave is continually being discovered. Air exchange studies estimate the total volume of the cave to be many times greater than what has already been discovered, and new leads are currently being explored to the south, east and west. All portions of the monument south of the Jewel Cave Fault, and adjacent U.S. Forest Service lands for two miles east and west, and one mile south, can reasonably be assumed to include discovered or undiscovered cave.

Four key needs provide a basis for the recommended actions in this plan:

- To improve understanding of the surface and groundwater hydrology as it involves water moving into and through the cave.
- To identify impacts to cave resources, and the origins of those impacts.

- To identify cave features and resources which are water dependent, and establish water rights for the flows necessary to sustain them.
- To ensure the long-term protection of water resources and cave features through establishment of a monitoring program.

Each of the actions proposed below address more than one need and are sensitive to all of them. The highest priority actions are those which will identify and mitigate impacts that are currently occurring, and support NPS claims for federal reserved and appropriative water rights. Scheduling for the water rights work is dependent on state progress on water rights adjudications. This situation will be monitored by the NPS Water Resources Division so that preparation and claims can be made in a timely manner.

### *Implications for Overall Monument Management*

In addition to the specific projects identified below, there are other actions that the monument can take to protect its water resources. Though management and staff are aware of most of these concerns, they are mentioned here to give added emphasis.

The monument should:

1. Implement actions proposed on the General Management Plan to reduce water resource impacts, specifically, replace wastewater system at the old headquarters, redesign the parking lot, and improve the sewage lagoons.



2. Pursue an outstanding resource waters designation from the state for waters in the cave.
3. Minimize surface management that alters vegetation and soil because this activity will change runoff and infiltration patterns.
4. Manage vegetation to retain and/or reestablish a natural density and species composition, and thereby maintain a natural level of evapotranspiration.
5. Recognize that all liquids and soluble solids spilled on the ground surface have a good likelihood of seeping into the cave.
6. Work closely with Black Hills National Forest to ensure that forest service personnel are aware of the location and sensitivity of cave resources, and are wary of management practices that might alter surface or groundwater hydrology. The monument should encourage forest management practices which maintain a natural forest density and species composition. The U.S. Forest Service should be discouraged from permitting activities which will involve a large amount of ground disturbance, vegetation loss, or use of herbicides in close proximity to the cave.
7. As in the past, work with the forest to facilitate mineral withdrawals for the protection of cave resources.

## *Additions to Monument Base and Staff*

Water quality and flow monitoring will be a continuing need and should be a base-funded responsibility of the monument. Given the location of developments and wastewater facilities over the cave, impacts to cave waters will be a continuing concern. Long-term monitoring will be necessary in order to identify possible impacts and their sources.

An estimated 0.7 FTE and an additional \$10,000/year of support funding will be necessary to carry out a basic water quality and flow monitoring program, and to administer special studies. The position should be filled by a GS-7 or GS-9 with a background in physical science, hydrology or a similar specialty. A portion of this position might be shared with Wind Cave which will have similar monitoring needs. The amount of staff commitment needed to carry out monitoring will be greater at Jewel Cave National Monument than at other non-cave parks because of the additional time needed to access and sample remote parts of the cave.

In order to quantify base-staffing needs for all parks, the NPS has developed the Resources Management Assessment Program (R-MAP). This generates an allocation of full-time equivalencies (FTEs) based on the resources within, and management setting of the park. Initial results are available for Jewel Cave and indicate that the monument resources management program is staffed at slightly less than one-fourth the current need (10.89 FTEs needed vs.

2.5 FTEs available). For water resources management the R-MAP indicates that only 0.1 FTE is needed while 0.4 FTE is currently committed. This discrepancy brings out two flaws in the system: (1) the allocation does not adequately account for the complexity of water resources management in a cave setting; and (2) the monument recognizes the need for water resources management and is committing staff there, while needs in other resource areas, such as vegetation, wildlife, fence, and pest management, are not being met. In spite of this, the overall allocation for the monument is a reasonable representation of the unmet need.

When R-MAP is incorporated into the Resource Management Plan for the monument, the need for water resources management should be explained. A proposed staffing plan could meet this need by either that addition of a shared water resources position with Wind Cave, or a new position to address other unmet needs that will free current staff to concentrate more on water resources.

### *Water Resources Management Planning*

A full Water Resources Management Plan is not recommended for Jewel Cave National Monument at this time. The issues facing the monument can be effectively addressed within this document and the RMP. Six project statements addressing the most pressing issues are provided in Appendix A of this report.

## **Project Recommendations**

### *Water Resources Monitoring* (See Project Statement JECA-N-020)

A water resources monitoring program is necessary for Jewel Cave due to the sensitivity of cave resources, changes in hydrologic conditions, and the effectiveness of water as a vehicle for transporting contaminants into the cave. Objectives of the monitoring program should be to:

1. Determine if cave waters are contaminated and identify sources of that contamination.
2. Improve the understanding of the cave's hydrology.
3. Establish a continuing database suitable for determining future trends.
4. Monitor the effects of changes in surface and cave management.

The current monitoring program is cooperatively funded by the NPS, the state of South Dakota, and EPA. When it is completed at the end of Fiscal Year 1994 protocols for a long-term monitoring program should have been developed and tested. At that time, a monitoring plan and rationale should be written and circulated for review among NPS specialists, state regulators, and academic specialists. The monitoring plan should include monitoring objectives, a quality control/quality assurance plan, budget and personnel constraints, and parameters and



schedules. The current database provides a test of techniques and data so that a statistically viable sampling design can be developed.

The monitoring program should be designed so that it will support the development of criteria for outstanding resource waters designation. It should also be based on the limits of acceptable change developed for cave resources. Parameters should be selected that will be sensitive to the types of contamination that might be expected while meeting the limitations of sampling in the cave. Potential contamination sources include domestic wastewater, parking lot and road runoff, road salting, highway spills, and underground storage tanks. Important characteristics of each of the parameters selected are likely to change if contamination is present; sampling and analysis costs are reasonable; standard analysis protocols can be met considering cave logistics; they are likely to be transported from the surface to the cave; and they are not so variable that an inordinate number of samples will have to be collected.

Fecal coliform or other bacteria are useful indicators of sewage contamination in some settings, but cannot be recommended for Jewel Cave. These and other bacteria are probably some of the more problematic indicators. There will be problems with transportation and analysis time, collecting a large enough sample in a reasonable time-frame to be useful and reportable, and collecting a sufficient number of samples to provide meaningful data. Other parameters with

less variability and greater mobility through the rock, such as ammonia, nitrate, phosphate, biochemical oxygen demand, or optical brighteners, will be better indicators of sewage contamination.

### *Surface and Groundwater Hydrology*

(See Project Statements JECA-N-021 and JECA-N-022)

The major focus of investigations into surface and groundwater hydrology should be to develop an understanding of the hydrologic systems affecting Jewel Cave in order to determine and predict the influence of surface developments. Previous studies conducted on the geology and groundwater hydrology of Jewel Cave provide a basis for understanding and point out the need for future studies. Some of the basic work conducted by Alexander et. al (1989), demonstrates a direct hydrologic connection between the surface and cave. Wiles (1992) established the location and flow characteristics of wet areas in the cave, and discussed the influence of vegetation and stratigraphy on flows in the cave.

Some questions which remain unanswered are:

- Does the nature and location of surface developments affect the location, timing, and amount of water reaching the cave? It is very apparent that surface developments affect drainage patterns locally at the surface, but whether these alterations are significant by the time the water

reaches the cave is not known. It may be that the distribution of flow is strongly influenced by stratigraphy and changes at the surface are not detectable by the time flow reaches the cave. Conversely, if flow is more strongly affected by shallow rock and soil characteristics, surface developments could have a profound effect. It is important to understand the influence of surface features on cave hydrology in order to determine if mitigation is needed, plan effective mitigation, and to predict the effects of any new developments.

- Are evapotranspiration rates a major factor influencing water quantity and quality in the cave? This relationship has been demonstrated to some extent, but further investigations should be able to demonstrate the effects with greater certainty and to help quantify the relationship. Alexander et al. (1989), attributed the relatively high Mg/Ca ratio in waters at Jewel Cave, in comparison to Wind Cave, to more effective evapotranspiration from the area's forest cover. If this is the case, then Mg/Ca ratios should change seasonally with ET rates and precipitation. ET was also a major component of the water budgeting by Wiles (1992). This information will advance the understanding of the influence of surface vegetation on the amount and quality of water in the unsaturated zone, and help guide vegetation and land management in the cave vicinity. Since ET may have an influence on water quality parameters, a better understanding of

it would help in explaining some of the natural variability measured in water quality.

- Do water quality constituents demonstrate as much variability in areas of the cave under surface developments as in undisturbed areas, indicating flow patterns have been altered? Changes in surface flow patterns may affect the amount of variation found in water quality parameters by changing the subsurface residence time for water. Even if mean values are not altered, variability might be.

Several specific actions can now be identified to address these questions. These actions will probably be revised and supplemented as current studies progress.

1. Determine if Mg/Ca ratios and conductance tend to vary with evapotranspiration rates. This analysis will require more frequent water sampling for some basic parameters (than would be done under the regular water quality monitoring program) and improved estimates of ET.
2. Investigate spacial differences in the variability of water quality. This investigation will require a water quality monitoring design which will provide a database large enough to allow statistical analysis to be conducted with a reasonable degree of certainty.
3. Investigate seasonal and short-term variations in the volume of flow as



a response to changes in precipitation and evapotranspiration. This investigation should require a regular flow monitoring program at several sites in the cave, and improved estimates of ET. Flow-monitoring sites should be selected which will represent drainage from a variety of surface topography and microclimate conditions. Three recording meteorological stations will be installed to monitor north-facing, south-facing, and valley bottom conditions.

4. Investigate pathways of water from the surface to the cave, in particular, lateral movements near the surface, and at depth.

### *Water Rights*

(See Project Statement  
JECA-N-025)

The status of water rights within the monument is unknown, though monument resources may be protected, in some measure, by both state appropriative and federal reserved water rights. Monument lands use to be U.S. Forest Service lands prior to designation of Jewel Cave National Monument. Presidential Proclamation No. 799 which created the monument recognized that "...the natural formation, known as the Jewel Cave...is of scientific interest, and it appears that the public interest would be promoted by reserving this formation as a National Monument, with as much land as may be necessary for the proper protection thereof..." The proclamation also states that monument status was not intended to prevent the use of lands for "...forest purposes under the proclamation of the Black Hills National Forest, but the two reservations shall

both be effective on the land withdrawn, but the National Monument hereby established shall be the dominant reservation." Consequently, federal reserved water rights appear to exist for monument and forest purposes.

State appropriative rights for water used on, or diverted from, monument lands need to be identified. It appears that the monument has certified water rights for domestic purposes which include, under state law, use for wildlife watering. In addition, the monument may have vested water rights under state law for wildlife watering based on land ownership and beneficial use which predates 1955. Whether state water rights can be used for protection of natural resource values other than wildlife watering is not known at present.

An investigation is needed to identify state appropriative rights presently certified for use on, or diversion from, monument lands; and an examination of alternative options to secure additional water rights to support monument purposes. A project statement for water rights is included in Appendix A. Surface water resources seem to be integrally related to cave resources and essential for their preservation. Proposed investigations into hydrologic patterns, the hydrologic history of Hell Canyon, and the adequacy of water supply wells for the monument will all assist in the determination of water rights.

## *Hydrologic Connections with Hell Canyon*

(See Project Statement  
JECA-N-024)

The hydrologic connection between Hell Canyon and the underlying Jewel Cave is not well understood. Portions of Jewel Cave under Hell Canyon contain features that are clearly water-related, such as pronounced water lines, deep silt deposits, a cut-bank, bottlebrushes, and other speleothems, which indicate a direct connection may have once existed between the drainage and the cave. A study of water-deposited sediments in the cave, and surface characteristics of the canyon would shed some light on the recent hydrologic history of the cave and the importance of surface hydrology in the development and maintenance of cave features.

Sediment deposits might shed some important light on the hydrologic history of Jewel Cave and Hell Canyon. Horizontal beds of fine silt are thickest under the canyons tapering to nothing as distances increase from the canyon. The regional groundwater table is currently several feet below the lowest known cave passages, and indicators of standing or flowing water are very rare in Jewel Cave. The age of the sediment deposits is not known, but they are more recent than the major crystal development and subsequent stalagmite formation. Deposits may be as recent as a few decades old, or date back to the ice age or earlier.

The nature of the deposition process is also not known. It may have resulted

from one or a few events, or slowly accumulated over a long period. Though the sediments were apparently deposited in standing water, it is not known whether the origin of this water was from Hell Canyon or the regional water table at a time when it was much higher. The origin of the sediments is also unclear and could be from sediments in Hell Canyon, redeposition of pockets of sediments in the Madison Limestone, or mechanical weathering inside the cave.

Another possible mode of deposition which could have occurred under today's climate conditions may have been a rare, and very large flood. The alluvium may have been scoured to a depth where water and fine sediment could move freely through fractures into the cave. Water would have had to enter so rapidly or in such volumes that, even in a karst system, it would pool long enough to settle the fine silt. If this event occurs periodically, then natural deposition patterns in the cave could be affected by land and vegetation management practices in the watershed.

A two-phase study of fluvial deposits in Jewel Cave and possible connection with surface flows in Hell Canyon is proposed. Phase I will focus on characterizing sediments in the cave, and initiate collection of groundwater data and anecdotal descriptions of the flows of Hell Canyon. Results of the first phase will indicate the need for Phase II. Phase II will attempt to confirm a hydrologic connection between surface flows and the cave, and include more extensive study of the history of sedimentation in Hell Canyon.



Objectives of the proposed action are to:

1. Determine if there is a hydrologic connection between surface flows in Hell Canyon and apparent fluvial deposits in the cave.
2. Determine the timing of flows, and if they remain an important process.
3. Identify the existence of water dependent features in portions of the cave near the canyons.
4. Find indicators of the flow regime of Hell Canyon, and determine if it has been significantly altered by human activity.

Following the proposed study, an examination of consumptive water uses and land management in the Hell Canyon Watershed might be in order.

### *Water Supply and Groundwater Monitoring*

(See Project Statement  
JECA-N-026)

Wells for the monument appear to be adequate for the foreseeable future, but it is possible that the water table may be slowly declining as a result of pumping by the monument and/or other wells in the area. Static water levels should be monitored at regular intervals in order to provide a basis for protecting the water supply and to avoid a future water supply crisis arising with little warning.

It may be possible to monitor static water levels in Well #1 while Well #2 is

operating, but the separation of only 400 feet probably does not provide sufficient isolation. It is more likely that both wells will have to be shut down for a few hours to allow the water to come to equilibrium before measurements are made. Once seasonal or daily patterns in groundwater levels and recovery rates are established by relatively frequent monitoring, the monitoring schedule can probably be cut back to a few representative measurements per year.

Funding is requested only for the above portion of this project, at this time. Once the groundwater table is encountered in the cave, a project statement should be written to request funding for the following action.

Groundwater monitoring should be conducted in the cave once the water table is encountered. Even though all 100 miles of known cave are above the water table, more cave passage is being discovered regularly, and it appears inevitable that the water table will be reached in the near future. Cave passages follow the southerly dip of the rocks so the water table should be intersected within one-quarter to one-half mile south of the current limit of mapped passage. With the maze-like nature of Jewel Cave (four layers of overlapping interconnected passages) it is likely that several pools will be found where the cave intersects the groundwater table. Jewel Cave has a geologic history of multiple inundations which are responsible for the formation of the cave and its subsequent spectacular mineralization. The natural processes of mineral deposition, erosion, or both, are probably occurring near the

contact-point of the cave and water table.

Once the groundwater table is encountered, a recording gauge and staff gauge should be installed in the cave at a pool connected directly with the water table. Both gauges would be operated during the initial phases of the monitoring program. The recording gauge will provide a record of short-term variations in water levels which will thus provide an indication of the reliability of staff gauge measurements for long-term monitoring. The data-logger should have the capability to store at least 30 days of data, so servicing can be kept to a minimum in the difficult-to-reach southern portions of the cave.

The recording gauge may be removed once water-level patterns are found to be constant enough to be accurately represented by occasional staff-gauge measurements. Monitoring frequency will be determined by water-level variability and the difficulty of reaching the site, possibly two to six times a year. First-year funding will require \$11,000 and 0.3 FTE for installation and operation. Long-term monitoring will require a base increase of \$2,700 and 0.1 FTE. Installation of this equipment in the cave will require an Environmental Assessment.

## Other Recommendations

### *Wastewater Disposal*

Water quality monitoring in the cave should be combined with regular inspections and maintenance of the wastewater system to insure that

problems with wastewater drainage into the cave do not reoccur. Dye traces may be used to investigate possible leaks, but the interval between tests will have to be sufficient to allow for a complete flushing from previous tests; probably several years.

If wastewater leaks become a chronic problem in spite of efforts to maintain a sealed system, consideration should be given to moving the wastewater treatment system some distance away from known cave. This will probably necessitate installation of lift stations and several miles of pipe, and cooperation of Black Hills National Forest in the siting of facilities.

### *Monument Facilities*

Relocation of most monument facilities away from known cave features was considered as an alternative in the General Management Plan which is currently under review. This alternative was dropped from consideration pending further evaluations of the impacts of existing facilities and efforts to mitigate them. Moving facilities to a new location is problematic because all lands in the vicinity are likely to be underlaid by cave. More of the cave is continually being discovered and air-flow studies indicate that it is many times larger than the area of mapped passages. If facilities were moved nearby, it is very likely they would overlie the cave, and have similar impacts on undiscovered passages. As an alternative, locating most facilities in Custer could be cumbersome because visitor services would still need to be provided at the cave.



## *Surface Water Quality*

Other than the sewage lagoons and three small springs, there are no permanent surface waters in the monument. Sampling of these features can be useful in exploring the connection and interaction of ground and surface waters, and monitoring the status of the springs. They should be part of the water quality monitoring program, and may be an important component of a study into hydrologic patterns. If investigations into water rights indicate a need for flow and water quality information in order to support claims, then a more rigorous monitoring effort will be needed.

Springs are important for the wildlife and vegetation they support. They are not used for human consumption and, with the exception of Prairie Dog and Jewel Cave springs which are located near the highway, these springs are not likely to be impacted. The springs have relatively small recharge areas which generally appear to be away from developments inside and outside the monument.

## *Highway Spills*

Risk of contamination resulting from highway spills will be greatly reduced by the proposed highway realignment. The highway will remain busy and will still be in close proximity to known cave passages, but the number of accidents should be greatly reduced. The monument should continue to provide emergency and spill-containment response to this stretch of highway as some accidents will still occur.

Other recommendations for future management of the roadway to protect water resources include the following:

1. During construction, base camps and service areas with fuel storage, and human waste disposal should be located away from known cave features. The only way to ensure that there are no caves, would be to locate these facilities six miles east of the monument where there is no limestone present. The EA and construction plans should address the location of construction camps and fuel storage. Spill response should also be addressed.
2. Sediment introduced into Hell Canyon during and after construction might clog solution conduits that carry water or sediment into the cave. Construction plans should include mitigation to minimize erosion and the introduction of sediment to the stream.
3. The monument should encourage the state to exclude the use of herbicides for roadside vegetation control and use only mowing or chopping, if needed.
4. The state should be encouraged to consider eliminating the use of road salt on this stretch of U.S. Highway 16. Cinders or sand traction agents could be used in place of salt mixtures.

## *Flood Hazards*

Though the risk of flooding was apparently a factor in the decision to

locate the visitors center and other monument facilities out of the canyon bottoms, no quantitative flood hazard analysis has been conducted for the monument. For very general planning purposes it can be assumed that the entire valley floors in both canyons are flood hazard areas. If, at some time in the future, locating facilities in the canyon bottoms is considered, a formal flood-hazard analysis should be undertaken.

### *Water Siphoning to Facilitate Cave Exploration*

Travel to the remote western regions of the cave once required removal of water from a pool so that cavers could avoid a complete drenching in the cool windy passages, and the risk of hypothermia.

The pool was drained by initiating a siphon which carried water down its natural drainage channel. Excavation of the "Very Important Short Cut" eliminated the need to use this passage for every trip to the western cave. Siphoning is now a rare activity, occurring less than once a year, and considered rather benign. No further action is recommended.

### *Coal Slurry Pipeline*

A proposal to slurry coal from the vicinity of the Black Hills to the lower Mississippi River Valley was made in the 1970s, but it is no longer being considered. The export of water pumped from the regional aquifer had the potential to impact the monument through lowering the water table in the area.

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In addition, the authors would like to Tom Willingham, of the U. S. Environmental Protection Agency for providing an overview of his agency's participation in the cave



water quality monitoring program. Hilair Peck, hydrologist for the Black Hills National Forest, provided a description of hydrologic conditions and land management practices on the forest.

Lastly, the authors would like to recognize the management and staff of Jewel Cave who have been particularly energetic in identifying and mitigating impacts to their cave resources. Their efforts over the past decade has been exemplary in the protection of the monument's resources, through diligence in understanding the importance of water resources to the cave and its natural function, identifying problems that existed, and taking steps to correct them.





# APPENDIX A

## PROJECT STATEMENTS

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JECA-N-020.000 Monitor Water Resources

JECA-N-021.000 Study Surface and Groundwater Interactions

JECA-N-025.000 Water Rights

JECA-N-024.000 Hydrologic Connections Between Jewel Cave and Hell Canyon

JECA-N-026.000 Monitor Groundwater Level

JECA-N-022.000 Restore Natural Hydrologic Patterns

Project statements are listed in priority order at the time of this report. They will be inserted in the monument's Natural and Cultural Resources Management Plan and among the other resource management priorities. The content and priority of project statements will be revised regularly as more information becomes available. The two projects assigned lowest priorities at this time can be expected to increase in priority if new cave discoveries reach the groundwater table, or other studies indicate a more immediate need for restoration of natural hydrologic patterns.





PROJECT NUMBER: JECA-N-020.000

TITLE: MONITOR WATER RESOURCES

FUNDING STATUS: FUNDED: 20.00 UNFUNDED: 64.50

SERVICEWIDE ISSUES: N12 WATER FLOW N11 WATER QUAL-EXT

CULTURAL RESOURCE TYPE CODE: N/A

10-238 PACKAGE NUMBER:

PROBLEM STATEMENT:

Water resource monitoring will be necessary at Jewel Cave for the foreseeable future. Given the proximity of developments and wastewater facilities over the cave, it is likely that there currently are, or will be future impacts to cave waters. Long-term monitoring will be necessary in order to identify possible impacts and their sources.

Three points demonstrate the importance of water to the monument: (1) water is an essential component of the cave environment and a key factor in the formation, maintenance and deterioration of speleothems, (2) water, its acquisition and disposal are necessary to provide for visitor use of the cave, and (3) water can be the predominant vehicle for carrying contaminants from the surface to the cave. Any alteration in the amount or quality of water flowing through the cave could cause irreversible impacts to some cave formations.

The monument is completing a two year project for monitoring water resources at Wind and Jewel Caves. It is jointly supported by the NPS Water Resources Division, State of South Dakota, and U.S. Environmental Protection Agency. Though results have not been fully evaluated, preliminary findings have documented hydrocarbons (including toluene, benzene, xylene, and oil and grease), and trace of the herbicide Tordon in cave waters. Additionally, some samples have been found to contain relatively high levels of lead, zinc, copper, chromium, and nickel (these may be the result of laboratory error because they were found in only one set of samples). For each of the agencies involved, the purposes of this project were:

\* Monument - To assess the quality of waters enroute to and in the Madison Aquifer, determine whether contamination of those waters occurs, determine patterns of infiltration of waters into the vadose zone and aquifer, and determine probable sources of contaminants that are found.

\* State of South Dakota - To investigate the quality of unpolluted waters in the Black Hills, and the occurrence of high

Proposal Date: 94

levels of several metals in Jewel and Wind Caves. Data from Jewel Cave will support their efforts to differentiate between naturally high levels of metals, in particular, lead, and polluted waters.

\* EPA - To investigate parameters useful for indicating road and parking lot runoff in caves, and to support the monument with training and laboratory analysis.

Samples were, and continue to be collected bi-weekly at ten of the most accessible sites, and quarterly at a total of twenty sites. Bi-weekly samples are analyzed in the park for nitrates, chloride and lead, and quarterly samples for major anions and cations, trace metals and ortho phosphate. The program also includes some dye tracing, and analysis of sediment deposits and bedrock as possible sources of elevated metals.

This project should be followed by a long-term monitoring program that will be supported in the park base. The costs will be slightly higher than in other parks because it takes several hours of travel-time to reach some of the remote wet areas in the cave, and the sample team must include at least three people for safety reasons.

#### DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY:

Based on the results of the current study, a plan for long-term monitoring will be developed by the monument with assistance from the NPS Water Resources Division, state, and EPA. The study plan will address a sampling design, parameters, quality control and quality assurance, data management and the need for specific studies. These are likely to be a continuing need because of the relatively poor understanding of unsaturated groundwater flow in general, and the hydrologic systems of Jewel and Wind Caves in particular. The scope of this program might include the volume and timing of flow, location of water resources, and water quality at sample sites which include cave waters, surface springs and (possibly) ephemeral channels.

Objectives of the monitoring program should be to:

1. Determine if cave waters are contaminated and identify sources of that contamination.
2. Improve the understanding of cave hydrology.
3. Establish a continuing database suitable for determining trends.
4. Monitor the effects of changes in surface and cave management.



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5. Develop a database sufficient to support limits of acceptable change criteria proposed in the GMP, and to support a state designation of outstanding resource waters.

This project will require an estimated 0.7 FTE, \$17,500 in salary and \$4,000/year of support funding to carry out a basic water quality and flow monitoring program, and to administer special studies. The position should be filled by a GS-7 or GS-9 in the fields of physical science or hydrology, or a similar specialty. The position, or a portion of it, might be shared with Wind Cave which will have similar monitoring needs. (Note: The R-MAP allocation for water resources in Jewel Cave is only 0.1 FTE, which reflects the near absence of surface water in the park. It does not accurately reflect the level of management needed for waters in the cave.)

## BUDGET AND FTEs:

-----FUNDED-----				
	Source	Act Type	Budget (\$1000s)	FTEs
Year 1:	WATER-RES	MON	20.00	0.0
	FED-OTHER	RES	0.00	0.0
	ST-LOCAL	RES	0.00	0.0
			-----	
		Subtotal:	20.00	0.0
Year 2:				
Year 3:				
Year 4:				
		Total:	20.00	0.0

-----UNFUNDED-----				
	Source	Act Type	Budget (\$1000s)	FTEs
Year 1:				
Year 2:	PKBASE-NR	MON	21.50	0.7
Year 3:	PKBASE-NR	MON	21.50	0.7
Year 4:	PKBASE-NR	MON	21.50	0.7
			=====	
		Total:	64.50	2.1

(OPTIONAL) ALTERNATIVE ACTIONS/SOLUTIONS AND IMPACTS: N/A

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COMPLIANCE CODE(s): EXCL

EXPLANATION: 516 DM2 APP. 2, 1.6

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PROJECT NUMBER: JECA-N-021.000

TITLE: STUDY SURFACE AND GROUNDWATER INTERACTIONS

FUNDING STATUS: FUNDED: 0.00 UNFUNDED: 36.40

SERVICEWIDE ISSUES: N12 WATER FLOW N21 CAVE RESOURCES

CULTURAL RESOURCE TYPE CODE: N/A

10-238 PACKAGE NUMBER:

PROBLEM STATEMENT:

An investigation is needed to determine how the interaction of surface and groundwater movements affects the location and amount of water reaching Jewel Cave. This will allow an evaluation of the impacts of surface facilities and land management on cave resources, and provide essential information to guide the mitigation of any impacts that are documented.

All monument facilities, including roads, visitors center, residences, maintenance area, parking lot, and sewage lagoons, are located over known cave passages. Previous investigations have documented rapid transmission of water from surface facilities, such as the parking lot and sewage system, into the cave. Water was found to travel from the surface to the interior of the cave through a complex pathway, arriving in a series of random pulses. This shows that the major transmission of water is not through open direct channels nor simple diffuse flow, but rather a combination of pathways.

Water quality monitoring in the cave has also detected evidence of contamination from the surface. Some of the most dramatic contamination problems, such as a leaking wastewater system, have been corrected, but more subtle avenues of contamination have yet to be fully documented and understood. These include possible contamination from road salting, parking lot runoff, highway spills and underground storage tanks. The presence of toluene, benzene, xylene, oil and grease, and the herbicide Tordon have been documented in cave water.

Water is important for maintaining the mineralogy and environment of the cave. Though most of Jewel Cave is dry, several wet areas occur near, but not necessarily under, the major surface drainages of Hell Canyon and Lithograph Canyon. Recent studies have found indications that water percolating from the surface is forced toward the drainages by a shale layer in the Minnelusa Formation. Where the shale surfaces several small springs occur and water is then free to resume flowing downward to the cave. Impermeable surfaces like the parking lot, roofs and roads have probably changed timing, amount and location of runoff. Whether

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this constitutes a significant impact to cave resources needs to be determined. Water quality monitoring currently being conducted by the monument will support this project.

The major focus of investigations into surface and groundwater hydrology should be to develop an understanding of the hydrologic systems affecting Jewel cave so that the influence of surface developments can be determined and predicted. Previous studies into the geology and groundwater hydrology of Jewel Cave provide a basis for understanding, and point out the need for future studies. Some of the basic work conducted by Alexander and others (1989) demonstrated a direct hydrologic connection between the surface and cave. Wiles (1992) documented the location and flow characteristics of wet areas in the cave, and investigated the influence of vegetation and stratigraphy on flows in the cave.

Questions which remain unanswered include:

\* Does the nature and location of surface developments affect the location, timing and amount of water reaching the cave? It is very apparent that surface developments affect drainage patterns locally at the surface, but whether these alterations are significant by the time the water reaches the cave is not known. It may be that the distribution of flow is strongly influenced by stratigraphy so that changes at the surface are not detectable by the time flow reaches the cave. Conversely, if flow is more strongly affected by shallow rock and soil characteristics, surface developments could have a profound effect. It is important to understand the influence of surface features on the cave's hydrology in order to determine if mitigation is needed, plan effective mitigation, and to predict the effects of any new developments.

\* Is evapotranspiration a major factor influencing water quantity and quality in the cave? This relationship has been demonstrated to some extent, but further investigations should be able to demonstrate the effects with more certainty and help quantify the relationship. Alexander and others (1989) attributed the relatively high Mg/Ca ratios in the waters of Jewel Cave to more effective evapotranspiration from the forest cover (in comparison to the grass cover at Wind Cave). If this is the case, then Mg/Ca ratios should change seasonally with ET rates and precipitation. ET was also a major component of the water budgeting by Wiles (1992). This information will advance the understanding of the influence of surface vegetation on the amount and quality of water in the unsaturated zone, and help guide vegetation and land surface management in the cave vicinity. Since ET may have an influence on water quality parameters, a better understanding of it would help in explaining some of the natural variability that may be occurring in water

quality.

\* Do water quality constituents demonstrate as much variability in areas of the cave under surface developments as in undisturbed areas, indicating flow patterns have been disturbed? Changes in surface flow patterns may affect the amount of variation found in water quality parameters by changing the subsurface residence time for water. Even if mean values are not altered from place to place, the variability might be.

As the GMP (near completion) for the monument is implemented, the understanding gained through this project will be useful in designing the proposed changes in facilities and mitigation for them.

#### REFERENCES

Alexander, E. C. Jr., M. A. Davis, and S. C. Alexander. 1989. Hydrologic Study of Wind Cave and Jewel Cave. Final Report. University of Minnesota. Contract no. CX-1200-5-A047. 196pp.

Wiles, Michael E.. 1992. Infiltration at Wind and Jewel Caves, Black Hills, South Dakota. Master's Thesis, South Dakota School of Mines and Technology. 50pp.

#### DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY:

A multifaceted study is proposed with the objective to determine the hydrologic patterns of infiltration and transmission to the cave, and identify impacts to natural hydrologic patterns from surface developments and management. Several specific actions can be identified to address these questions. Some will probably be revised as current studies progress.

1. Determine if Mg/Ca ratio and conductance tend to vary with evapotranspiration rates. This will require more frequent water sampling (than would be done under regular water quality monitoring) for some basic parameters and improved estimates of ET.

2. Investigate spacial differences in the variability of water quality. This will require a statistical analysis and an enhancement of the water quality monitoring program with more frequent sampling.

3. Investigate seasonal and short-term variations in the volume of flow as a response to changes in precipitation and evapotranspiration. This will require regular flow monitoring at several sites in the cave and improved estimates of ET. Flow monitoring sites will be selected which will represent drainage



from a variety of surface topography and microclimate conditions.

4. Three recording meteorological stations will be installed to monitor north-facing, south-facing and valley bottom conditions. They will monitor precipitation, temperature, relative humidity, wind speed and wind direction.

5. Measurements or frequent estimates of flow from springs and seeps in the cave vicinity will be made. This may require some minor modifications at the spring sites, such as thinning some vegetation, but the springs will not be developed or permanently confined in order to get a measurement.

6. Continued accurate mapping of wet areas in the cave and measuring or estimating flow rates. Flows will be measured where physically possible and the data is necessary to support other components of this study.

Some aspects of this study will be carried out by an independent contractor with experience in investigating unsaturated flow and karst hydrology. It will complement and make use of data collected under the monument's water resource monitoring program.

The logistics of working in remote areas of the cave will make data collection more complicated and expensive. Where appropriate, the final report will include recommendations for changes in surface facilities necessary to protect or restore natural flows in the cave. Natural flow conditions will have to be deduced from a comparison of portions of the cave with differing levels of impact from surface activities, because no unimpacted baseline is available.

BUDGET AND FTEs:

-----FUNDED-----				
Source	Act	Type	Budget (\$1000s)	FTEs
Year 1:				
Year 2:				
Year 3:				
Year 4:				
Total:			0.00	0.0

-----UNFUNDED-----				
Source	Act	Type	Budget (\$1000s)	FTEs
Year 1:	WATER-RES	RES	19.40	0.7

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Year 2:	WATER-RES RES	17.00	0.7
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Year 3:

Year 4:

	=====		
Total:		36.40	1.4

(OPTIONAL) ALTERNATIVE ACTIONS/SOLUTIONS AND IMPACTS: N/A

COMPLIANCE CODE(s): EXCL

EXPLANATION: 516 DM2 APP. 2, 1.6

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PROJECT NUMBER: JECA-N-025.000

TITLE: WATER RIGHTS

FUNDING STATUS: FUNDED: 0.00 UNFUNDED: 6.00

SERVICEWIDE ISSUES: N13 WATER RIGHTS N12 WATER FLOW

CULTURAL RESOURCE TYPE CODE: N/A

10-238 PACKAGE NUMBER:

PROBLEM STATEMENT:

The status of water rights within the monument is unknown. Monument lands were U.S. Forest Service lands prior to designation of JECA. The proclamation that created the monument recognized that "...the natural formation, known as the Jewel Cave...is of scientific interest, and it appears that the public interest would be promoted by reserving this formation as a National Monument, with as much land as may be necessary for the proper protection thereof..." The proclamation also stated that monument status was not intended to prevent the use of lands for "...forest purposes under the proclamation of the Black Hills National Forest, but the two reservations shall both be effective on the land withdrawn, but the National Monument hereby established shall be the dominant reservation." Consequently, Federal reserved water rights appear to exist for monument and forest purposes.

State appropriative rights for water used on, or diverted from, monument lands need to be identified. It appears that the park has certified water rights for domestic purposes which include, under state law, use for wildlife watering. In addition, the monument may have vested water rights under state law for wildlife watering based on land ownership and beneficial use that predates 1955. Whether state water rights can be used for protection of natural resource values other than wildlife watering is not known at present.

Surface water resources have been shown to be integrally related cave hydrology and cave resources. Mineral formations are being actively deposited in some of the wet areas of the cave. The presence and distribution of water affects cave climate which is essential for the maintenance cave minerals.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY:

A project will be conducted with the assistance of the Water Resources Division to:

1. Determine the status of water rights in JECA and to examine

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the dependence of park purposes and resources on water. The results of JECA-N-021 Determine Surface and Groundwater Hydrology, and JECA-N-024 Investigate Historic Flows of Hell Canyon will provide useful information in support of this project.

2. Examine options to secure additional water rights to support park purposes. Options may include some combination of state appropriative and Federal reserved water rights.

## BUDGET AND FTEs:

-----FUNDED-----			
Source	Act Type	Budget (\$1000s)	FTEs
Year 1:			
Year 2:			
Year 3:			
Year 4:			
Total:		0.00	0.0

-----UNFUNDED-----			
Source	Act Type	Budget (\$1000s)	FTEs
Year 1:	WATER-RES RES	6.00	0.0
Year 2:			
Year 3:			
Year 4:			
Total:		6.00	0.0

(OPTIONAL) ALTERNATIVE ACTIONS/SOLUTIONS AND IMPACTS: N/A

COMPLIANCE CODE(s): EXCL

EXPLANATION: 516 DM2 APP. 2, 1.6

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PROJECT NUMBER: JECA-N-024.000

TITLE: HYDROLOGIC CONNECTIONS WITH HELL CANYON

FUNDING STATUS: FUNDED: 0.00 UNFUNDED: 31.70

SERVICEWIDE ISSUES: N12 WATER FLOW

CULTURAL RESOURCE TYPE CODE: N/A

10-238 PACKAGE NUMBER:

PROBLEM STATEMENT:

The hydrologic connection between Hell Canyon and the underlying Jewel Cave is not well understood. Hell Canyon is the major ephemeral stream channel that cuts across the western portion of the monument passing roughly 50 feet over several passages of Jewel Cave. A study of water-deposited sediments in the cave and surface characteristics of the canyon would provide insights into the recent hydrologic history of the cave and the importance of surface hydrology in the development and maintenance of cave features.

Hell Canyon is a major drainage, 500 - 600 feet deep, extending for several miles up and downstream of the monument. It is difficult to conceive that Hell Canyon was carved under the current flow regime because observed stream flows are rare and relatively small. No quantitative streamflow information is available. Hell Canyon may have formed under a wetter climatic regime when it was supported by the regional groundwater table. Sediments in Jewel Cave may be a preserved record of that period.

Beds of water deposited sediment found in cave passages in the vicinity of Hell Canyon indicate that there might be some connection between the stream and cave, but the origin and age of these deposits is not known. The deposits might shed some important light on the hydrologic history of Jewel Cave and Hell Canyon. Horizontal beds of fine silt are thickest under the canyons, tapering to nothing as distances increase from the canyon. The regional groundwater table is currently located several feet below the lowest known cave passages and indicators of standing or flowing water are very rare in Jewel Cave.

The age of the sediment deposits is not known, but they are more recent than the major crystal development and subsequent stalagmite formation. They may be as recent as a few decades old, or date back to the ice age or before.

The nature of the deposition process is also not known. They may have resulted from one or a few events, or slowly accumulated over a long period. Though the sediments were apparently



deposited in standing water, it is not known whether the origin of this water was a from Hell Canyon or at a time when the regional water table was much higher. Their origin is also unclear and could be from sediments in Hell Canyon, redeposition of pocketed sediments in the Madison Limestone, or mechanical weathering inside the cave.

Another possible mode of deposition which could have occurred under today's climatic conditions is that a rare and very large flood scoured the alluvium in the bed of Hell Canyon to a depth where water and fine sediment could move freely through fractures into the cave. Water would have had to enter so rapidly or in such volumes that, even in a karst system, it would pool long enough to settle the fine silt. If this occurs periodically, then natural deposition patterns in the cave could be affected by land and vegetation management practices on the watershed.

#### DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY:

A two phase study of fluvial deposits in Jewel Cave and possible connection with surface flows in Hell Canyon would be undertaken.

The first phase will focus on characterizing sediments in the cave, and initiating the collection of groundwater data and anecdotal descriptions of the flows of Hell Canyon. Results of the Phase I will indicate the need for Phase II, which will attempt to confirm a hydrologic connection and include more expensive study of the history of sedimentation in Hell Canyon. Each phase will have several elements, listed below.

Objectives of this action are to: Determine if there is a hydrologic connection between surface flows in Hell Canyon and apparent fluvial deposits in the cave; determine the timing of flows and if they remain an important process; identify the existence of water-dependent features in portions of the cave near the canyons; and find indications of the flow regime of Hell Canyon, and if it has been significantly altered by human activity.

#### Phase I Actions.

1. Inventory and describe the locations, depositional characteristics and morphology of the cave sediments near Hell Canyon. This will include mapping, describing cross-sections, and describing drip and channel features that indicate the depth, velocity, and duration of flows and/or inundation.
2. Inventory wet areas and water dependent features in the vicinity of Hell Canyon, and consider the dependence of these features on flows that produced the sediment deposits. Portions of this inventory has been completed, but will be examined in greater detail with an emphasis on the relationship of possible

flows from Hell Canyon and the existence of the features.

3. Collect samples of cave sediment deposits and possible source areas, and compare their size composition, mineralogy, chemistry, particle shape, and other characteristics to determine the source of deposits.

4. Drill four shallow monitoring wells in the alluvium of Hell Canyon. These wells will bottom at bedrock and allow us to determine whether there is significant water moving through the alluvium in Hell Canyon. Wells would be spaced along the bed of Hell Canyon from north of the Jewel Cave Fault, downstream to the confluence with Lithograph Canyon. One of the wells should be located as closely as possible, over the cave passages where fluvial sand is found. Well elevations will be surveyed and depth-to-water measured biweekly through the spring and summer, and monthly for the remainder of the year.

5. Collect oral histories from old-timers and written descriptions which provide insights into historic flow patterns of Hell Canyon.

The duration of Phase I is planned to last one year. Well measurements will continue for another year whether or not Phase II is initiated because flow is so dependent on variable weather conditions that a single year's data may not be useful.

Phase II will be initiated if the analysis of Phase I shows that sediment deposits in Jewel Cave are relatively recent and originate from the bed of Hell Canyon, indicating there is at least an intermittent connection between water and sediments in Hell Canyon and the interior of Jewel Cave. Phase II will provide further documentation of the hydrologic connection to the cave and the sedimentation and flooding history of Hell Canyon. This will allow a determination of whether deposits from Hell Canyon are a recent phenomena or a relict from past climatic regimes. Phase II will include:

1. A dye-tracer study with dye released in Hell Canyon and collected in the cave. This will probably have to be conducted when Hell Canyon is dry because it is that way almost all of the time. Investigators should be prepared to respond in case the opportunity presents itself to release dye, and sample during a flood event.

2. Determine the alluvial history of Hell Canyon, including where possible, the age of sediments and an indication of the flood history. This will require digging some trenches or pits and auger holes in the bed of the canyon to obtain one or more cross-sectional views. Where carbon or tree-ring dating is possible, these will be used to date deposits.

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Though Phase I could probably be conducted under a categorical exclusion, it should be combined with Phase II in a single Environmental Assessment in order to avoid delays once the study is underway.

## BUDGET AND FTEs:

-----FUNDED-----				
	Source	Act Type	Budget (\$1000s)	FTEs
Year 1:				
Year 2:				
Year 3:				
Year 4:				

			=====	
	Total:		0.00	0.0

-----UNFUNDED-----				
	Source	Act Type	Budget (\$1000s)	FTEs
Year 1:	WATER-RES	RES	14.60	0.4
Year 2:	WATER-RES	RES	17.10	0.3
Year 3:				
Year 4:				

			=====	
	Total:		31.70	0.7

(OPTIONAL) ALTERNATIVE ACTIONS/SOLUTIONS AND IMPACTS: N/A

COMPLIANCE CODE(s): EA

EXPLANATION:

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PROJECT NUMBER: JECA-N-026.000

TITLE: MONITOR GROUNDWATER LEVEL

FUNDING STATUS: FUNDED: 0.00 UNFUNDED: 2.90

SERVICEWIDE ISSUES: N12 WATER FLOW N13 WATER RIGHTS

CULTURAL RESOURCE TYPE CODE: N/A

10-238 PACKAGE NUMBER:

PROBLEM STATEMENT:

The level of the groundwater table is important to the preservation of cave resources and to the water supply at Jewel Cave. Levels should be monitored in the monument's two wells at this time, and in the cave when passages are discovered which reach the groundwater table.

Wells for the monument are meeting current needs and appear to be adequate for the foreseeable future. It is possible that the water table may be slowly declining as a result of pumping by the monument, or due to other wells in the area. Water levels should be monitored at regular intervals in order to provide a basis for protecting the water supply and to avoid a future water supply crisis from arising without warning.

Water for the monument is obtained from two wells; the first was drilled to 700 feet as a test well in 1959, the second was drilled in 1984 to a depth of 810 feet. Pumping from the first well could be sustained at only 8 gallons per minute, because drawdown was excessive at higher rates. The water supply proved to be inadequate in the 1980s following increases in visitation and staff, so a second well was drilled to a depth of 810 feet deep with the pump set at 560 feet. Static water level at the time of drilling was 420 feet below the surface. This well was tested at up to 80 gpm with the water level stabilizing at 523 feet below the surface. The well is currently pumped at 17 gpm in the summer, with the period of pumping reduced in the winter or when Well #2 is shut down and replaced with pumping from Well #1.

While some drawdown tests have been conducted on the monument wells, long-term monitoring of static water levels have not been conducted.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY:

Static water level will be measured regularly in one of the park wells, probably Well #1. Additional funding will be needed to support bi-weekly measurements during the first year. Thereafter,

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depth to water measurements might only be needed 2-4 times per year, depending on the aquifer characteristics discovered in the first year of monitoring. Monitoring will require shutting down both wells for several minutes or a few hours to allow the water to come to equilibrium. It is assumed that the wells are too close together to allow accurate measurements in one while the other is being pumped, but this can be tested during the regular monitoring.

## BUDGET AND FTEs:

-----FUNDED-----			
Source	Act Type	Budget (\$1000s)	FTEs
Year 1:			
Year 2:			
Year 3:			
Year 4:			
Total:		0.00	0.0

-----UNFUNDED-----			
Source	Act Type	Budget (\$1000s)	FTEs
Year 1:	NR-I&M MON	2.00	0.1
Year 2:	PKBASE-OT MON	0.30	0.0
Year 3:	PKBASE-OT MON	0.30	0.0
Year 4:	PKBASE-OT MON	0.30	0.0
Total:		2.90	0.1

## (OPTIONAL) ALTERNATIVE ACTIONS/SOLUTIONS AND IMPACTS:

No Action. If wells are not monitored, a drop in the water table could occur and be undetected by the park until the drinking water supply is threatened. The regional aquifer is not well understood in this area so a drop in the water table resulting from park or external pumping would be hard to predict. Monitoring will provide the NPS with data necessary to demonstrate damage should pumping elsewhere cause the water table to fall.

COMPLIANCE CODE(s): EXCL

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EXPLANATION: 516 DM2 APP. 2, 1.6

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PROJECT NUMBER: JECA-N-022.000

TITLE: RESTORE NATURAL HYDROLOGIC PATTERNS

FUNDING STATUS: FUNDED: 0.00 UNFUNDED: 0.00

SERVICEWIDE ISSUES: N06 LAND USE PRAC N12 WATER FLOW

CULTURAL RESOURCE TYPE CODE: N/A

10-238 PACKAGE NUMBER:

PROBLEM STATEMENT:

This project is intended to follow JECA-N-021 which will study surface and groundwater interactions of Jewel Cave. Mitigation measures may be needed if that study demonstrates a connection between the numerous land disturbances and activities above the cave, and changes in the amount, location or quality of water reaching the cave.

Water is one of the most critical resource concerns facing the monument because it is an effective vehicle for transporting contaminants from the land surface into the cave. All monument facilities, including roads, visitor center, residences, maintenance area, parking lot and sewage lagoons, are located over known cave passages. Previous investigations have documented rapid transmission of water from surface facilities, namely the parking lot and sewage system, and the cave. Water from the surface was found to arrive in the interior of the cave in a series of pulses, indicating transmission is not through direct open channels or simple diffuse flow, but rather a combination of pathways.

Water quality monitoring in the cave has also detected evidence of contamination from the surface. Some of the most dramatic contamination problems, such as a leaking wastewater system, have been corrected, but more subtle avenues of contamination have yet to be fully documented and understood. These include possible contamination from road salting, parking lot runoff, and highway spills.

Water is important for maintaining the mineralogy and environment of the cave. Though most of Jewel Cave is dry, several wet areas occur near, but not necessarily under, the major surface drainages of Hell and Lithograph Canyons. Recent studies have found indications that water percolating from the surface is moved toward the drainages by a shale layer in the Minnelusa Formation. Small springs occur where the shale forces water to the surface. Impermeable surfaces like the parking lot, roofs and roads have probably changed the timing, amount and location of runoff and infiltration. Whether this constitutes a

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significant impact to cave resources has yet to be determined.

Long-term water resources monitoring will provide a means of assessing the success of actions instituted in this project.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY:

Actions will be developed with the objective of restoring natural hydrologic patterns in the cave. These might include: replacing the parking lot surface with a more permeable material, capturing and possibly treating parking lot runoff, changing salt use practices on US Highway 16, changing road drainage to enhance infiltration, and correcting any leaks found in the water or wastewater systems. In each case, the action will be tied to an impact reasonably attributable to some surface feature or activity.

No cost estimates are included at this time. Most actions envisioned as part of this project will require an Environmental Assessment.

BUDGET AND FTEs:

-----FUNDED-----			
Source	Act Type	Budget (\$1000s)	FTEs
Year 1:			
Year 2:			
Year 3:			
Year 4:			
Total:		0.00	0.0

-----UNFUNDED-----			
Source	Act Type	Budget (\$1000s)	FTEs
Year 1:			
Year 2:			
Year 3:			
Year 4:			
Total:		0.00	0.0

(OPTIONAL) ALTERNATIVE ACTIONS/SOLUTIONS AND IMPACTS: N/A

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COMPLIANCE CODE(s): EA

EXPLANATION:

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## APPENDIX B

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### Budget profile for JECA-N-021 Study Surface And Groundwater Interactions

Element	Year 1	Year 2
1. <u>Additional Analysis for Basic Parameters</u> 12 Samples x 6 Stations @ \$40/sample for analysis @ \$100/sample for collection	10,000	10,000
2. <u>Statistical Consultation</u>		4,000
3. <u>Install Flow Recorders</u> Use modified recording rain gauge 4 gauges at \$800 each \$1,000/year operation	4,200	1,000
4. <u>Install 3 Recording Rain Gauges</u> \$800 each \$1,000/year operation & Installation \$500/year operation year 2	3,400	500
5. <u>Spring Flow Measurements</u> 6/year for 5 springs \$50/ measurement Purchase small flume \$300	1,800	1,500
6. <u>Continued Wet Area Mapping</u> No additional Cost	0	0
	<hr/> 19,400	<hr/> 17,000
FTE for installation, sample collection, maintenance, and analysis	0.7 FTE	0.7 FTE







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As the nation's principal conservation agency, the Department of the Interior has the responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

